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INFORMAL REPORT

UNDERSEA STUDIES WITH THE DEEP RESEARCH VEHICLE DEEPSTAR-4000

MARCH 1969

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ABSTRACT

The U.S. Naval Oceanographic Office used the Westinghouse submersible DEEPSTAR-4000 for 13 dives during October and November 1967. Marine geology, biology and the physical properties of the water column were studied on the 10 deep dives of this series.

These dives were accomplished along the east coast of the United States and in the Caribbean. Great similarities in the bottom features at widely separated sites as well as dissimilarities in adjacent areas are particularly noteworthy.

During this operation DEEPSTAR-4000 was evaluated as a Deep Oceanographic Survey Vehicle (DOSV). The lack of an all-weather capability and the rather limited payload hampered this study but the overlapping fields of the viewports and the ability to operate in very close proximity to the bottom regardless of terrain, are desireable features that should be included on any future DOSV.

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TABLE OF CONTENTS

	Page
ABSTRACT	i
FIGURES	iv
TABLES	vi
INTRODUCTION	1
PURPOSE OF THE STUDY	1
THE SUBMERSIBLE DEEPSTAR-4000	3
DIVE PROCEDURES	3
Pre-dive Sequence	3
Submerged Operation	6
Post-dive Sequence	7
Emergency Procedures	8
DIVE OBJECTIVES AND RESULTS	10
Objectives	10
Results	10
Dive 1	15
Dive 2	17
Dive 3	19
Dive 4	25
Dive 5	25
Dive 6	35
Dive 7	40
Dive 8	46
Dive 9	52
Dive 10	58
SUBMERSIBLE DESIGN CHARACTERISTICS AND PERFORMANCE	60
Viewports	60
Speed	62
Payload	63
Operating Depth	64
Endurance/Power	64
Habitability	65
Buoyancy Control	65
Maneuverability	66
Maintenance and Serviceability	67

TABLE OF CONTENTS (Cont'd)

	Page
SENSOR AND INSTRUMENT PERFORMANCE	67
Navigation	69
Depth and Altitude Sensors	69
Communications	70
Manipulator and Bottom Sampling Devices	70
Illumination	71
Photography	71
Oceanographic Sensors	72
SURFACE SUPPORT	72
SUMMARY AND CONCLUSIONS	76
Launch and Retrieval	76
Navigation and Positioning	77
Vehicle Characteristics	78
REFERENCES	79
ACKNOWLEDGEMENTS	79
APPENDIX I	80

FIGURES

1.) DEEPSTAR-4000 during launch from M/V SEARCH TIDE 2

2.) Schematic profile of DEEPSTAR-4000 5

3.) Dive site positions during NAVOCEANO operation 13

4.) Bathymetry in the area of Dive No. 1 16

5.) Slump scar along the valley flank 16

6.) Bathymetry in the area of Dive No. 2 18

7.) Turbidity resulting from contact with the bottom 18

8.) Echo-sounder record along the dive track 20

9.) Sketch of the meandering ridge feature 20

10.) Bathymetry in the area of Dive No. 3 20

11.) Manganese block about 6 inches thick 22

12.) Manganese blocks on the Blake Plateau 22

13.) View of large sand wave 22

14.) Sketch of Blake Plateau topography 23

15.) Ocean Bottom Scanning Sonar (OBSS) 24

16.) OBSS record from the Blake Plateau 24

17.) Nodule; francolite with aragonite partings 24

18.) Anglerfish in DEEPSTAR's "orange-peel" sampler 26

19.) Bathymetry in the area of Dive Nos. 4 and 5 26

20.) Sediment and manganese gravel at a depth of 3800 feet ... 28

21.) The calcite - quartz crust over manganese-sand suite 28

22.) Broken manganese pavement at a depth of 3750 feet 29

23.) Coral (or Corallina) growth on large manganese boulders . 29

24.) Manganese pavement and sediment with skeletal content ... 29

25.) Sketch of part of the Blake Escarpment 31
26.) Bottom samples from Dives 4 and 5 32
27.) Bathymetry in the area of Dive No. 6 36
28.) Ripple marks at a depth of 2500 feet 36
29.) Example of scour depressions and sediment shadows 38
30.) Large calcarenite boulder at a depth of 1000 feet 38
31.) Bottom sample from Dive No. 6 38
32.) Sketch of bottom features near Cay Sal 39
33.) Apparently blind spiny lobster seen at a depth of 2500 feet ... 41
34.) Bathymetry in the area of Dive No. 7 41
35.) Nearly flat, silty bottom 42
36.) Near-vertical escarpment with small sand streams 42
37.) Limestone (?) outcrop at a depth of 2500 feet 44
38.) Outcrop or boulders with some evidence of scouring 44
39.) Well-rounded, weathered reef - 1550 feet deep 44
40.) Basket sponges growing on manganese pavement 45
41.) One of the reef-like ridges encountered 45
42.) Sketch of major bottom features near Isla de Cozumel 47
43.) Echo-sounder record along Cozumel track 48
44.) OBSS record at Cozumel 48
45.) Bottom samples from Cozumel 49
46.) Bathymetry in the area of Dive No. 8 49
47.) Carbonate boulder at a depth of 3700 feet 51
48.) Carbonate boulder in a local depression 51

49.) Near-vertical rock scarp at a depth of 2400 feet 51

50.) Echo-sounder record from Misteriosa Bank 53

51.) Bathymetry in the area of Dive No. 9 53

52.) Limestone outcrop and adjacent sand ripples 55

53.) Marginal escarpment photographed through fogged port 55

54.) Sketch of marginal escarpment at Rosalind Bank 56

55.) Bottom samples from Rosalind Bank area 57

56.) Bathymetry in the area of Dive No. 10 59

57.) DEEPSTAR-4000 during recovery at night 61

58.) Viewport and camera port arrangement 61

59.) Normal positions of personnel 68

60.) Fairings removed from DEEPSTAR for ease of maintenance 68

61.) Releasable manipulator on DEEPSTAR 68

62.) M/V SEARCH TIDE 73

TABLES

I. DEEPSTAR-4000 Characteristics 4

II. Operation Summary 11

III. Dive Positions 14

IV. Support Personnel 75

INTRODUCTION

The U.S Naval Oceanographic Office conducted a series of dives using the Westinghouse manned submersible DEEPSTAR-4000 (Figure 1) during October and November of 1967. The purpose of the dives was to conduct geological and biological observations, and to measure various physical properties of the water column along the dive tracks. During the 32-day lease, commencing at New London, Connecticut and terminating at the Panama Canal, it had been planned to make 28 deep dives along the east coast of the United States and in the Caribbean area. However, due to adverse weather conditions and unexpected maintenance time, only 10 deep dives and 3 shallow dives were conducted.

PURPOSE OF THE STUDY

NAVOCEANO, presently engaged in a study to determine the optimum design characteristics for a Deep Oceanographic Survey Vehicle (DOSV) capable of operating to 20,000 feet, is also conducting *in situ* environmental oceanographic surveys. In addition to determining vehicle characteristics, experimental oceanographic sensors are being fabricated and operational techniques developed. To gain the operational experience necessary for performance of these objectives, a variety of currently available Deep Research Vehicles (DRV) is being used to conduct various field tests and surveys. The most desirable features of these craft, as well as oceanographic sensors, operational procedures, and support systems are being sought. DEEPSTAR-4000 is the fifth vehicle to be so employed by NAVOCEANO.

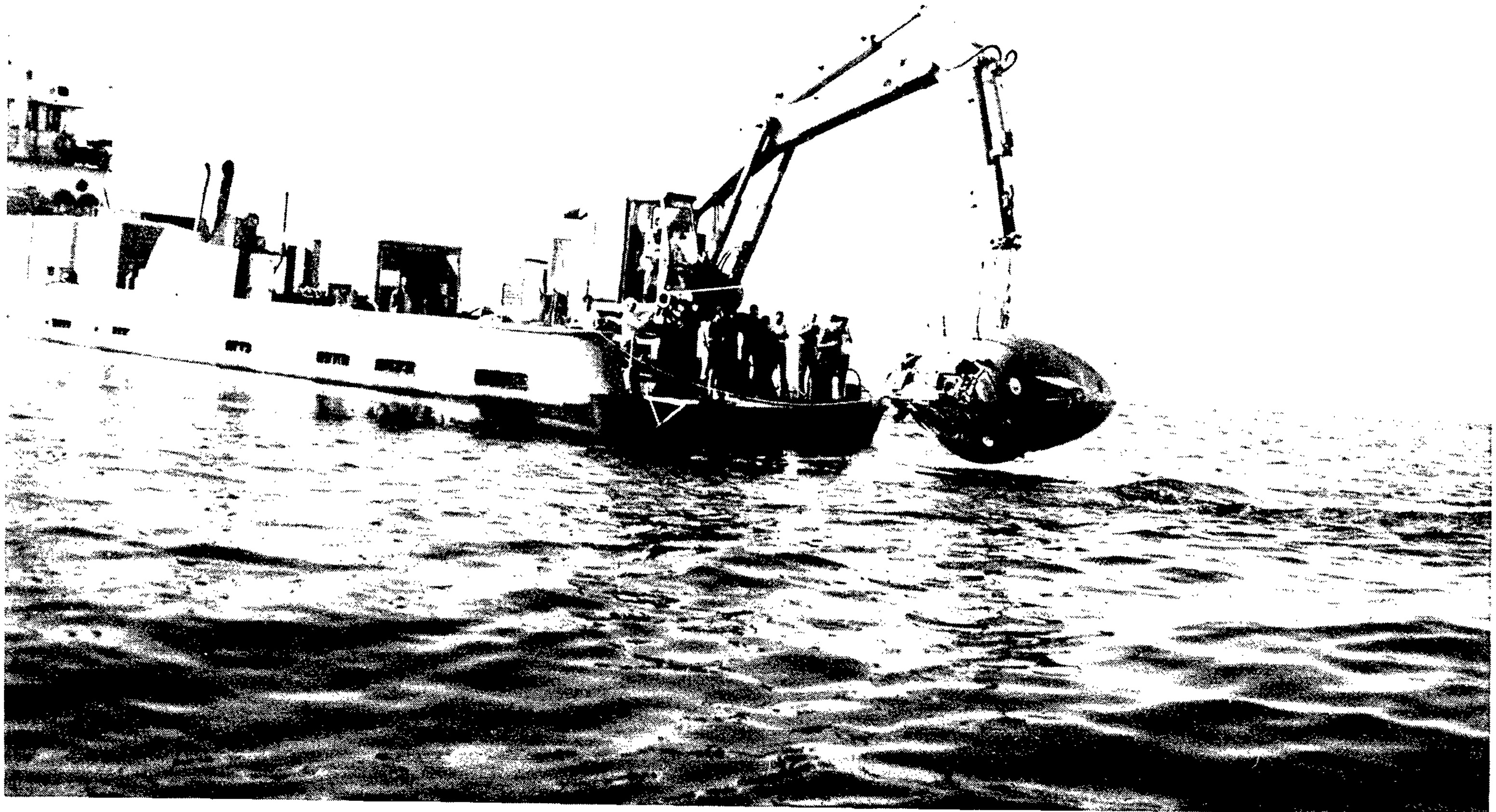


FIGURE 1. DEEPSTAR-4000 DURING LAUNCH FROM M/V SEARCH TIDE

THE SUBMERSIBLE DEEPSTAR-4000

Designed by the Westinghouse Corporation in collaboration with Jacques Cousteau, DEEPSTAR-4000 is a deep diving research vehicle based on Captain Cousteau's DIVING SAUCER. An evaluation of DEEPSTAR's operational performance at sea is presented in this report through a description of typical dive procedures and the actual NAVOCEANO dive results. A detailed discussion of structure, control, and electronics is not included. Major design features of DEEPSTAR, however, are presented in Table I and shown in the schematic profile in Figure 2.

DIVE PROCEDURES

Prior to this NAVOCEANO operation, DEEPSTAR-4000 had successfully completed 296 dives. The dive procedures that have evolved from this experience play an important role in the safe and efficient operation of the submersible.

Pre-dive Sequence

Before arriving on station, the pilot performs a pre-dive check of the submersible. This pre-dive inspection includes checking the operation of hydraulic and propulsion systems, the emergency battery for the underwater telephone, and all life support equipment. The pinger, which is battery-operated and used for tracking, is re-installed, oil in the batteries is topped off, and a visual inspection of the exterior components of the vehicle is made. Fiberglass fairings on DEEPSTAR are replaced, and a small boat containing the tracking and surface/sub-surface communications system is launched. The passengers are briefed on the operation of the emergency breathing equipment and various charac-

TABLE I

DEEPSTAR-4000 CHARACTERISTICS

VEHICLE:

LENGTH	18 feet
BEAM	10 feet
HEIGHT	7 feet
CREW	One Operator - Two Observers
MAXIMUM OPERATING DEPTH	4,000 feet
SPEED	Normal 1 knot Full 3 knots
WEIGHT IN AIR	19,000 pounds
ENDURANCE	12 hours at normal battery discharge rate
LIFE SUPPORT	48 man hours endurance
PAYLOAD	450 pounds

SYSTEMS:

PROPULSION AND STEERING	Two 4.5 hp reversible AC motors
POWER SOURCE	Three Lead-acid 400 amp-hr batteries
DEPTH CONTROL & BUOYANCY	Droppable weights and auxiliary tanks
TRIM CONTROL	Mercury trim system
NAVIGATION	Gyrocompass, fathometers, speed, depth indicators, and forward-looking sonar
COMMUNICATIONS	Underwater telephone and CB radio

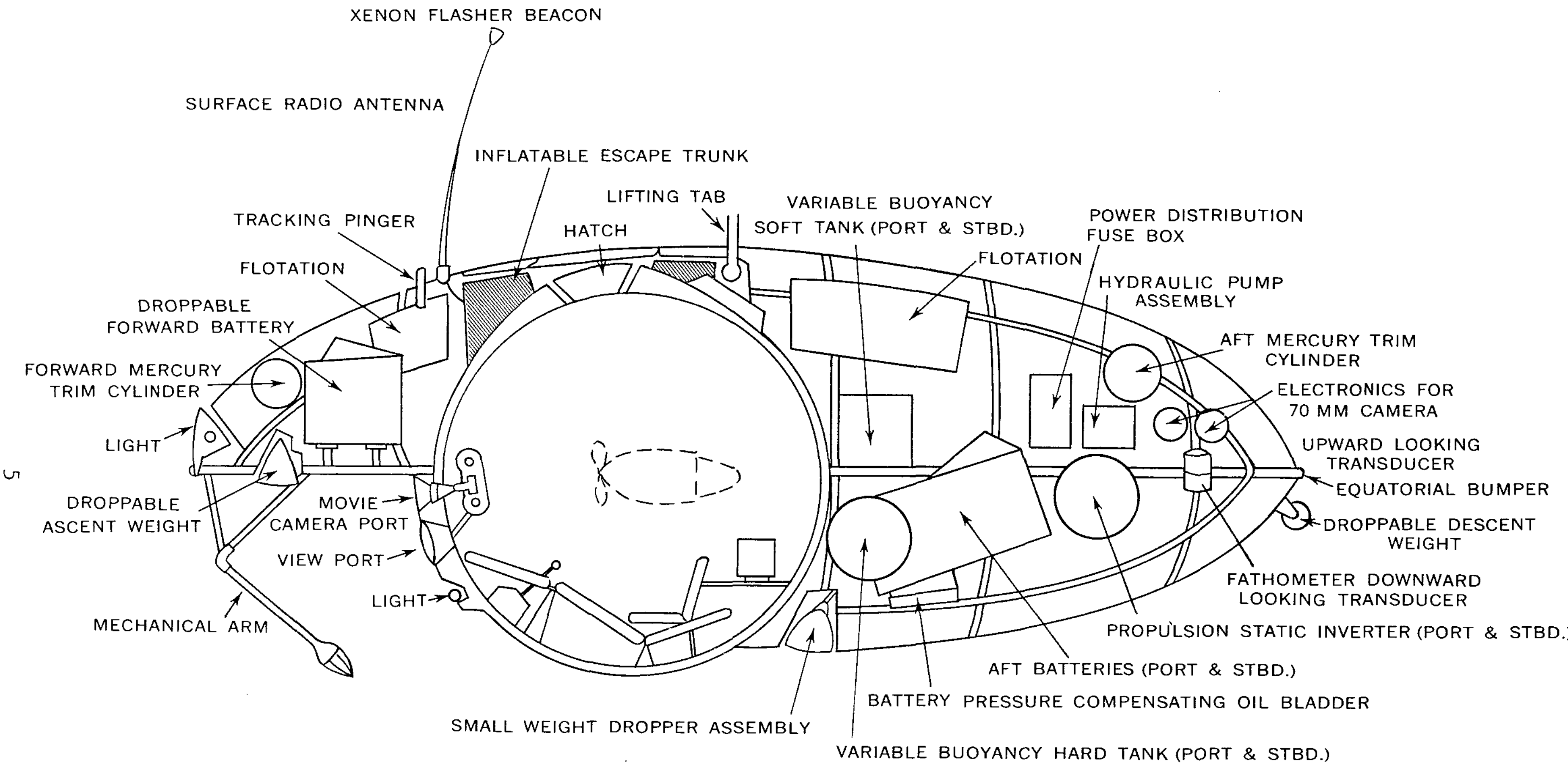


FIGURE 2. SCHEMATIC PROFILE OF DEEPSTAR-4000

teristics of the submersible. The pilot and observers then enter the sphere and position themselves for the dive.

In preparation for launching, the handling crane is moved into the proper position and the vehicle attached. After the stern of the ship is put into the sea, the master notifies the operations officer when all is ready for launching. The vehicle is lifted off the pad, put into the water, and released from its hook but still suspended just below the surface by a nylon tag line. Two divers release fore and aft handling lines, and make a visual exterior check of the vehicle to assure that all appears in normal operating condition. In some cases, scientific equipment is attached while the submersible is on the tag line. After a signal to the pilot from the diver assures that all is well on the exterior of the vehicle, the pilot, having made his check of all systems inside the submarine, confirms underwater telephone communication with the support ship. Underwater tracking established, the operations officer informs the pilot that all is in readiness for the dive. Next, the pilot signals the divers to release the tag line and the vehicle commences its descent.

Submerged Operation

Normal descent pattern is a helical spiral with about 3 revolutions per minute and approximately a 22° down angle in the stern. Descent rate is about 80 feet per minute. During descent the pilot checks his depth with either a pressure gage or an upward-looking echo sounder. Half way through the descent, the pilot changes to the downward-looking echo-sounder to monitor his altitude. At approximately 150 feet from the bottom, he releases a 220-pound lead descent weight, pumps mercury forward to

assume a horizontal attitude within the boat, and slowly approaches the bottom. During descent the pilot notifies the surface every 300 feet as to the operating condition of the submersible.

After reaching the bottom, communication checks are on a 30 minute schedule assuming there are no operational requirements that require more frequent communication. The dive mission is then pursued as previously outlined.

During the mission, tracking is accomplished by training a directional hydrophone from the surface which receives signals from a 27kHz pinger attached to the submersible. The surface tracking boat attempts to maintain a position directly over the submersible throughout the dive. Range to the submarine is obtained with the UQC (underwater telephone). During the NAVOCEANO operation off the east coast of the United States, the support ship used Loran-A for its geographic position and the relative position of the small tracking boat was obtained from the mother ship SEARCH TIDE by radar range and bearing. This yielded a rough approximation of the submersible's geographic position.

The mission completed, the pilot drops a 187 pound cast iron ascent weight and rises to the surface in a helical spiral at a rate of 50 feet per minute. During the dive, and particularly during ascent, SEARCH TIDE stays a half mile or more from the tracking boat.

Post-dive Sequence

After DEEPSTAR reaches the surface, the tracking boat closes on the vehicle, confirms surface radio communication, and determines

that all is well. The support ship moves into recovery position and, when DEEPSTAR is approximately 70 feet away, swimmers attach the nylon tag line. While DEEPSTAR is being pulled in under the crane, the swimmers receive the fore and aft steadying lines from the support ship and attach them to DEEPSTAR. DEEPSTAR is pulled into the proper attitude under the crane and the divers make the final hook-up to DEEPSTAR's lifting shackle. After DEEPSTAR is lifted free of the water, the ship gets underway to stabilize the deck. When stabilization is obtained, DEEPSTAR is swung aboard and placed into its cradle. The cradle is pneumatically adjusted to accept DEEPSTAR and the vehicle is secured. The pilot and observers leave the submersible and post-dive check-off and maintenance for the next dive begins.

After each dive, the vehicle is washed down with fresh water, oil is removed from the batteries, the pilot's log is checked for reports of any malfunctions, and necessary repairs are performed. The battery charge requires up to 8 hours, and replenishment of the oxygen supply follows. Lithium-hydroxide packages in the CO_2 scrubbers are replaced, ascent and descent weights are readied, and trim weights are restocked. One portion of the post-dive checkout and maintenance consists of installation and checking of customer equipment needed on the forthcoming dive.

Emergency Procedures

If tracking and voice communications are lost for a period of 30 minutes during the dive, the vehicle will surface. The purpose of 30 minute intervals is to assure that possible adverse drift between

the vehicle and the submersible will not be too great. On occasion, the submersible has been on the surface for several hours before being located by the support ship.

If the submersible descends in water depths in excess of 4,000 feet, an aluminum shear pin which shears at 4,300 feet, causes a spring-loaded actuator to mechanically drop the ascent and descent weights automatically returning the vehicle to the surface. Should release of the descent and ascent weights not cause the submersible to surface as planned, it is possible to jettison the entire small weight trim system, (177 pounds total). In addition, the mercury in the trim system (194 pounds) can be jettisoned. Under extreme negative buoyancy situations, the forward battery package, which weighs a total of 500 pounds in water can be jettisoned. Should the manipulator become entangled, it too is droppable. All of the above noted emergency systems can be dropped mechanically. At neutral trim a positive buoyancy of 1,058 pounds can be obtained by employing all the aforementioned emergency systems. Egress from the vehicle on the surface can be accomplished by inflating an escape trunk which protrudes 4 feet above the top of the submersible. The submarine carries a 3-man life raft, life jackets, survival food kit, flares, and emergency water. Should the interior atmosphere become toxic, oxygen rebreathers are available which have a life support duration of approximately 90 minutes. For night location on the surface the submersible has a xenon flashing light and a radio beam transmitter for radio direction finding from the support ship. A radar transponder is planned for installation in the near future.

DIVE OBJECTIVES AND RESULTS

Since the 32-day lease required transit from New London, Connecticut to Washington, D.C. and then to the Canal Zone, plans for 28 dives were made prior to the beginning of the mission. This was considered to be the maximum number of dives possible, based on ideal weather and assuming no major malfunctions occurred throughout the lease period. Table II is the actual operation summary and clearly demonstrates the effect of weather and maintenance on an idealized schedule.

Objectives

The primary objective of the operation was to become familiar with DEEPSTAR-4000 in order to evaluate her performance as an oceanographic survey platform. Difficulties associated with an extended at-sea submersible operation also were to be assessed and a variety of new instruments and techniques employed.

Of equal importance with this hardware evaluation, a number of scientific objectives were specified. Most dives involved a bottom transit normal to the contours for geology reconnaissance and bottom sampling, studies of near-bottom physical properties including sound velocity, temperature, water clarity and current velocity, and biological investigations in the water column and along the bottom transits.

Results

The scientific results of NAVOCEANO's 10 deep dives with DEEPSTAR are summarized below. Dive site positions are shown in Figure 3, and listed in Table III.

TABLE II

OPERATION SUMMARY

DATE	Dive No.	Event	Max.Depth (feet)	Duration	Observers
10/26		In port New London due to adverse weather at dive site.			
10/27	1	Investigation in Babylon Valley north of Hudson Canyon	3950	4hrs.24min.	R.Busby & J. Cohen
10/28		Adverse weather			
10/29		Transit for Washington, D.C.			
10/30		In port Washington, D.C. installing NAVOCEANO equipment			
10/31		In port Washington, D.C.			
11/1		In port Washington, D.C.			
11/2		Depart D.C. To Norfolk Canyon Area			
11/3	2	Investigations Norfolk Canyon	3700	6hrs.23min.	M.Costin & R.Merrifield
11/4		Inclement weather Return to Little Creek for Installation of gyrocompass			
11/5		On station, Norfolk Canyon No dive, Adverse weather			
11/6		On station, Norfolk Canyon No dive, adverse weather Underway for next dive site			
11/7		Adverse weather			
11/8		Adverse weather			
11/9	3	Investigation of manganese on Blake Plateau	1500	4hr.22min.	P.Bockman L.Hawkins

DATE	Dive No	Event	Max.Depth (feet)	Duration	Observers
11/10	4	Biological Investigation on the Blake Escarpment	3660	6hr03min	B. Zahuranec M. Fagot
11/11	5	Bottom investigations on the Blake Escarpment	3800	6hr43min	R. Merrifield P. VanSchuyler
11/12		Adverse weather			
11/13		Adverse weather			
11/14		Adverse weather			
11/15		In port Ft. Lauderdale maintenance			
11/16		In port Ft. Lauderdale maintenance			
11/17		In port Ft. Lauderdale maintenance			
11/18	6	Investigations at Cay Sal	2840	6hr22min	M. Costin L. Hawkins
11/19		At Key West site, using SEARCH TIDE to drag for camera array and OBSS for object location. No dive			
11/20		Transit from Key West to Cozumel			
11/21	7	Investigations on east side of Cozumel	3300	5hr38min	R. Merrifield M. Costin
11/22		Three (3) shallow dives for photography on w. side of Cozumel			
11/23	8	Investigation Misteriosa Bank	3900	3hr26min	R. Busby L. Hawkins
11/24	9	Investigation at Rosalind Bank	1900	4hr33min	M. Costin A. Pruna
11/25	10	Investigation at Roncador Cay. Dive aborted soon after reaching bottom	3600	1hr51min	L. Hawkins P. Bockman
11/26		Transit to and arrival at the Panama Canal			

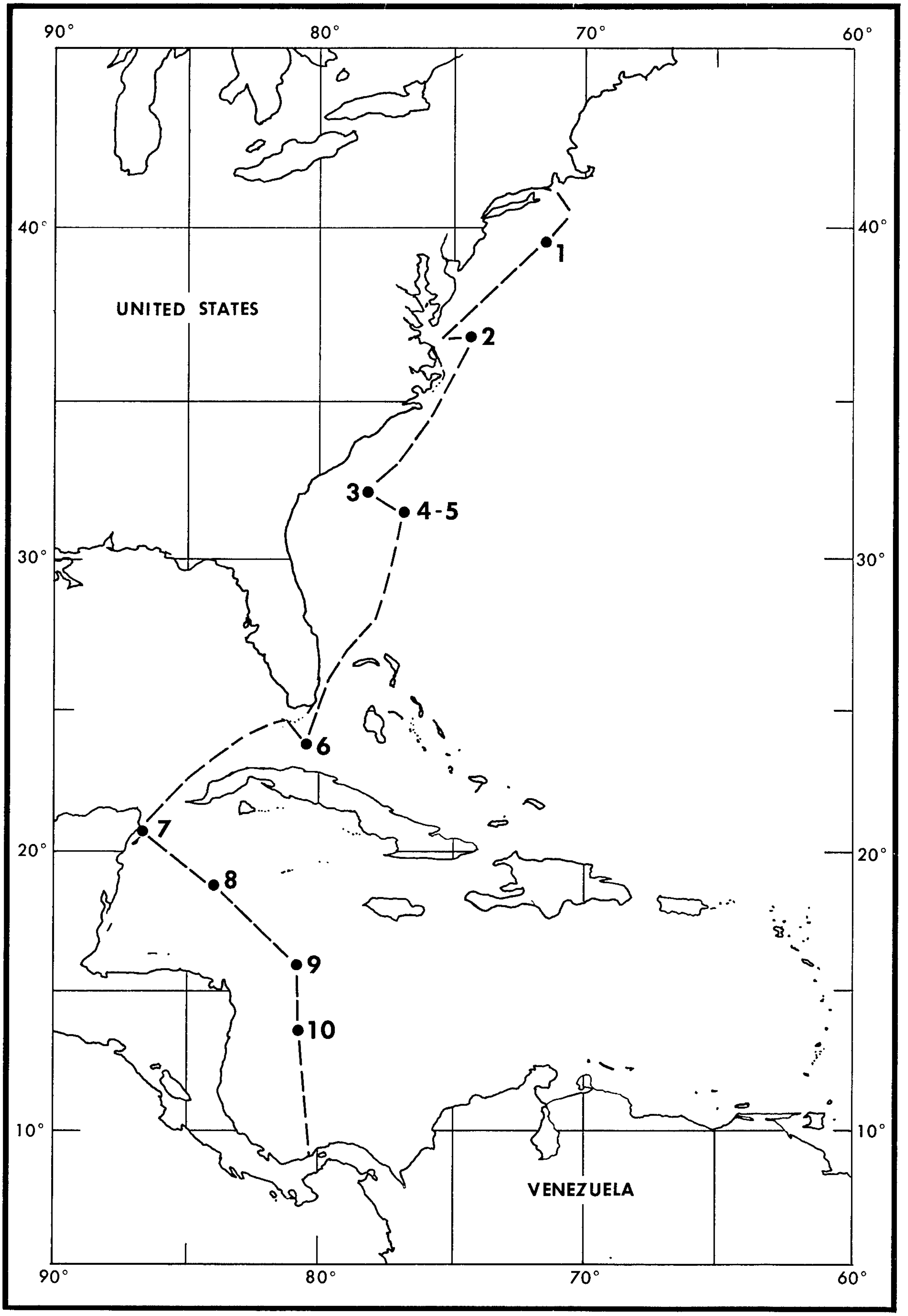


FIGURE 3. DIVE SITE POSITIONS DURING NAVOCEANO OPERATION

TABLE III

DIVE POSITIONS

Dive No.	Date	Area	Loran-A		Position	
			Descent	Ascent	Descent	Ascent
1	10/27/68	N. of Hudson Canyon	1H4-4797 1H5-2324	1H4-4794 1H5-2325	39°29.0'N 71°54.9'W	39°28.5'N 71°54.9'W
2	11/3/68	N. of Norfolk Canyon	1H4-2517 1H5-2923	1H4-2515 1H5-2933	37°06.8'N 74°27.0'W	37°07.8'N 74°29.9'W
3	11/9/68	Blake Plateau	1H6-3655 1H7-4500	1H6-3638 1H7-4498	32°00.2'N 78°30.6'W	32°00.9'N 78°28.3'W
4	11/10/68	Blake Escarpment	1H6-3226 1H7-3974	1H6-3230 1H7-3977	31°21.3'N 77°17.1'W	31°21.4'N 77°18.0'W
5	11/11/68	Blake Escarpment	1H6-3227 1H7-3967	1H6-3230 1H7-3975	31°20.5'N 77°17.2'W	31°21.0'N 77°18.0'W
6	11/18/68	Cay Sal	-	-	23°58.5'N 80°30.0'W	23°58.2'N 80°28.0'W
7	11/21/68	Cozumel	-	-	20°15'N 86°52'W	20°18'N 86°54'W
8	11/23/68	Misteriosa Bank	-	-	18°53'N 83°57'W	18°52'N 83°56'W
9	11/24/68	Rosalind Bank	-	-	16°00'N 80°37'W	16°01'N 80°35'W
10	11/25/68	Roncador Cay	-	-	13°35'N 80°08'W	Same Position

DIVE NO. 1

Location: Babylon Valley, N. of Hudson Canyon (Figure 4)

	Descent	Ascent
Position:	39°29.0'N 71°54.9'W	39°28.5'N 71°54.9'W
Local time:	0840	1304
Water Depth	3600 feet	3950 feet

Geology. DEEPSTAR bottomed at a depth of 3600 feet on the northeast side of Babylon Valley. The bottom, composed of an unconsolidated tan silty clay, sloped down to the southwest at about 30°. Essentially void of major relief features, the smooth bottom was interrupted by occasional 8 to 12 inch diameter burrows and mounds. Proceeding southwest downslope toward the valley axis the bottom remained smooth, but the slope increased to about 40°. At a depth of 3850 feet the slope increased to about 60° and the first of a series of presumed slump scars (Figure 5), about 6 to 8 inches deep, were observed. These scars in the unconsolidated sediment ran parallel to the depth contours and no outcrops were observed. At a depth of 3950 feet DEEPSTAR changed course to the southeast along the valley flanks. On this course, a series of four terraces was encountered. These terraces, each about 10 feet high and essentially parallel to the contours, had loose slabs of rock 3 to 4 inches thick exposed at their base. Samples were taken with the vehicle's manipulator but they either missed the sample basket or were removed by wave action when the vehicle surfaced.

Physical properties. Water temperature was 3.1°C and there was no discernible current where DEEPSTAR first encountered the bottom at 3600 feet. At 3800 feet a current setting to the southwest downslope

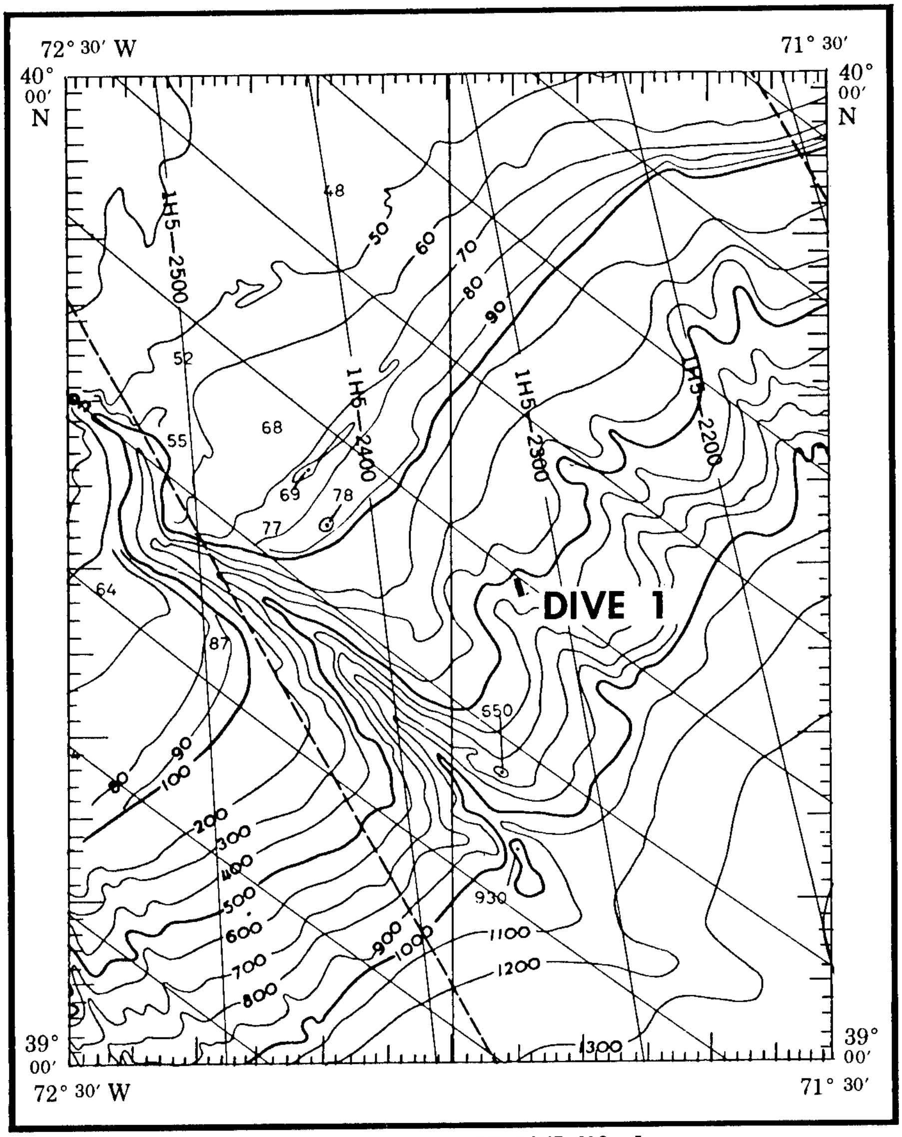


FIGURE 4. BATHYMETRY IN THE AREA OF DIVE NO. 1

FIGURE 5. SLUMP SCAR ALONG THE VALLEY FLANK

toward the valley axis was observed and estimated at 0.1 knot. At 3950 feet a 0.1 knot current was noted setting upslope to the northwest and parallel to the valley axis. Visibility was generally 30 to 40 feet when using the vehicle's 2500 watt lamp. Stirring of the sediment either by DEEPSTAR or organisms, however, reduced this range significantly.

Biology. The most significant biological observations included a large myctophid population, first sighted at 900 feet, increasing with depth and reaching a maximum of about 5 to 10 individuals per cubic meter at a depth of 1800 feet during descent. No myctophid concentration was noted during ascent. Also, a broadbill swordfish (Xiphias sp.) 6 to 8 feet long was sighted at 2600 feet.

DIVE NO. 2

Location: Continental Slope, N. of Norfolk Canyon (Figure 6)

	Descent	Ascent
Position:	37°06.8'N 74°27.0°W	37°07.8'N 74°29.9 W
Local time:	0735	1330
Water Depth:	3700 feet	2400 feet

Geology. Bottoming at a depth of 3700 feet in sediments very similar to those of Babylon Valley (tan silty clay), DEEPSTAR proceeded in a westerly direction upslope along a meandering ridge. The bottom sediment was easily disturbed by vehicle contact (Figure 7). The slope of the crest of this ridge varied between 0° and 20° during the transit from 3700 feet to 2400 feet. At no time were any outcrops encountered although a few solitary boulders, usually in depressions on the ridge

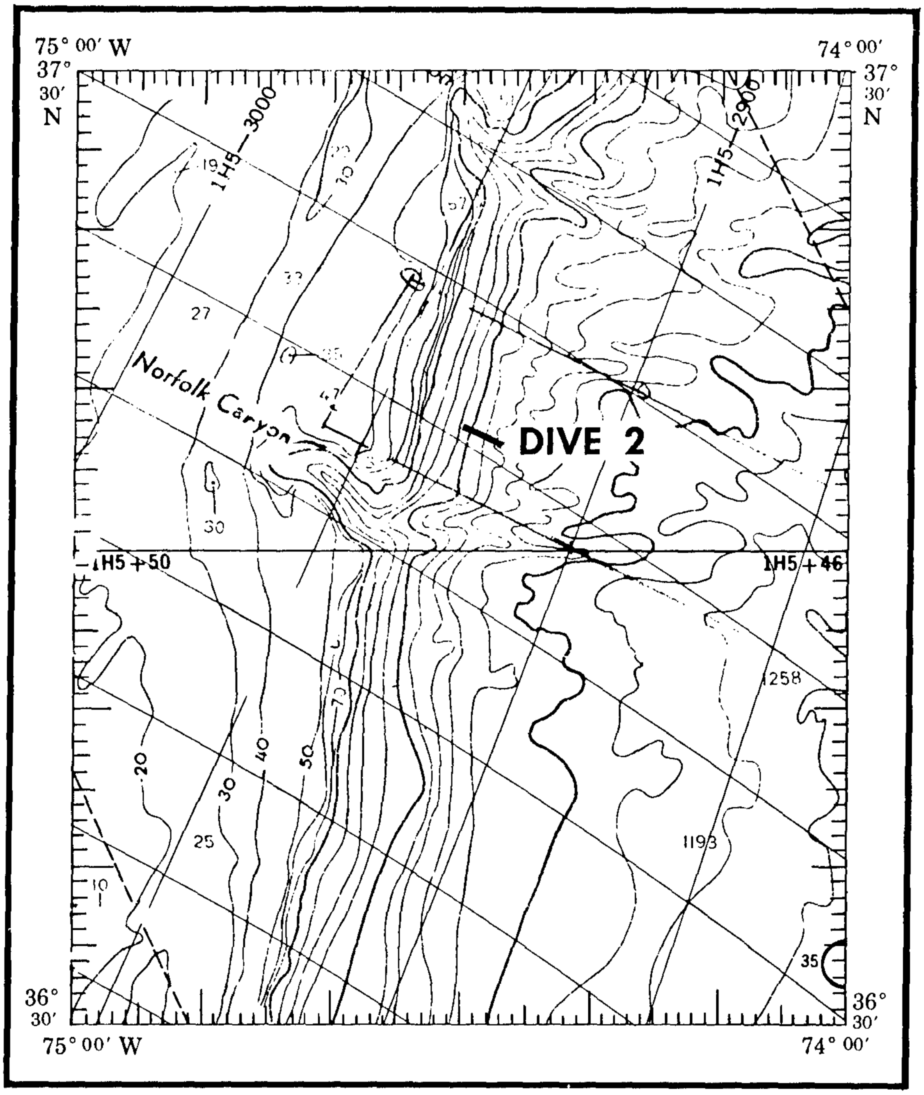


FIGURE 6. BATHYMETRY IN THE AREA OF DIVE NO. 2

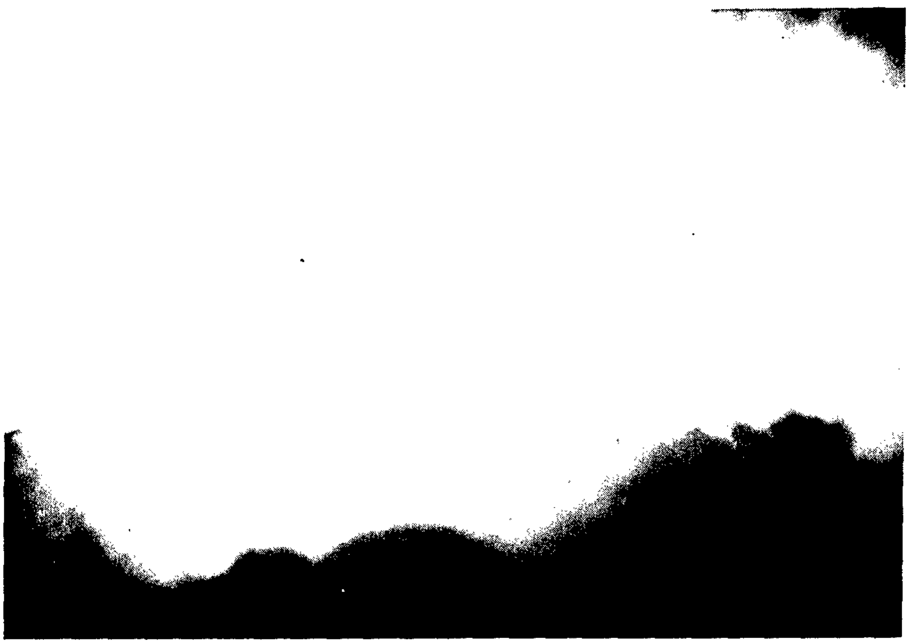


FIGURE 7. TURBIDITY RESULTING FROM CONTACT WITH THE BOTTOM

crest, were observed. The ridge was generally smooth except for some small animal mounds and throughout its length had a rounded crest. At times the slope of the ridge flanks approached 0° but usually was about 20° and the maximum slope observed was near 30°. Sediments appeared to be slightly more coarse (fine-grained sand vs. silty clay) at the western end of the transit. Figure 8 is the echosounder record from SEARCH TIDE along DEEPSTAR's track and Figure 9 is a sketch of the typical topography in this area based on actual observations.

Physical properties. Water temperature was between 4.0°C and 4.2°C throughout the bottom transit from 3700 feet to 2400 feet. Only negligible currents (<0.1 knot) were encountered and these appeared to be setting to the south. As on the previous dive, visibility was 30 to 40 feet unless the sediments, disturbed by the vehicle, caused zero visibility.

Biology. A concentration of myctophids was encountered between 900 and 1200 feet during descent. During transit upslope a broadbill swordfish (Xiphias sp.) was sighted at 2900 feet and again at 2700 feet. A large number of anemones were observed growing on the solitary boulders along the ridge crest.

DIVE NO. 3

Location: Blake Plateau (Figure 10)

	Descent	Ascent
Position:	32°00.2'N 78°30.6'W	32°00.9'N 78°28.3'W
Local time:	1045	1509
Water Depth:	1500 feet	1500 feet

Geology. DEEPSTAR landed at a depth of 1500 feet on a flat, nearly

FIGURE 8. ECHO-SOUNDER RECORD ALONG THE DIVE TRACK

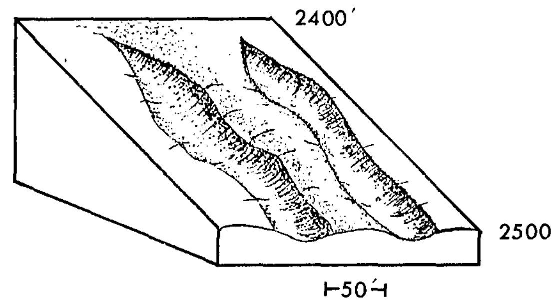


FIGURE 9. SKETCH OF THE MEANDERING RIDGE FEATURE

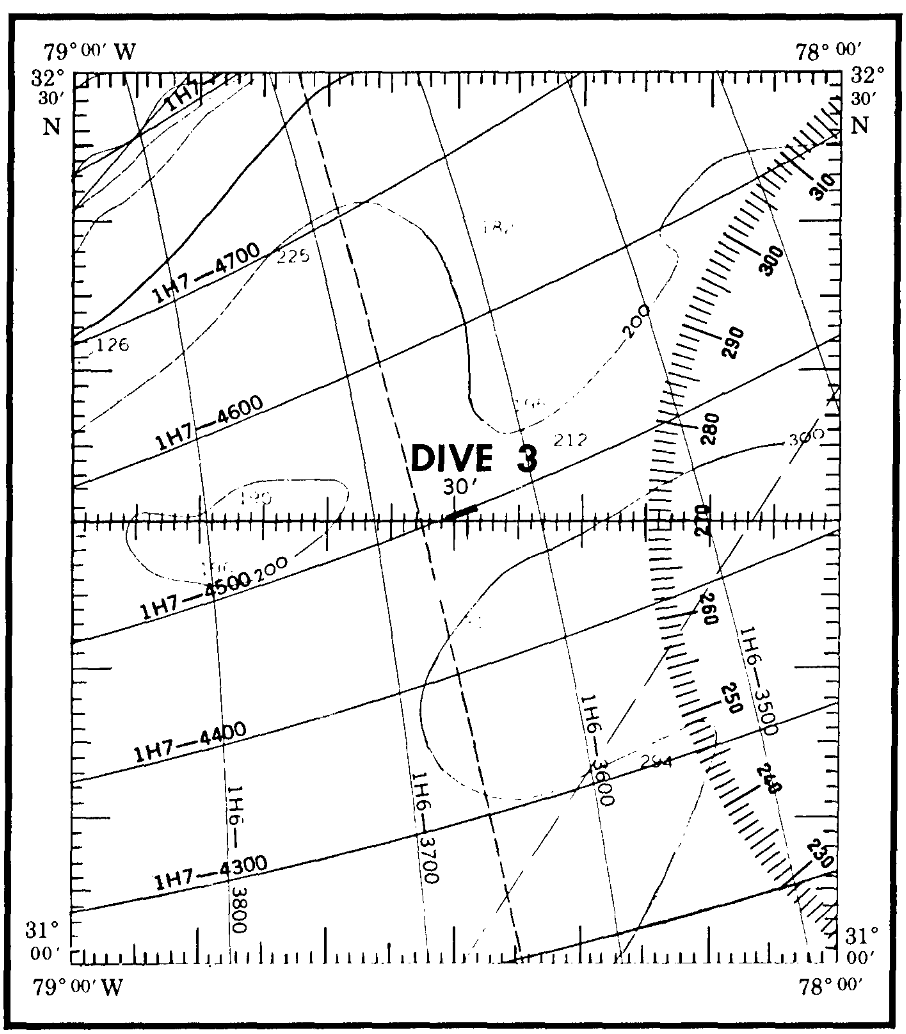


FIGURE 10. BATHYMETRY IN THE AREA OF DIVE NO. 3

featureless bottom covered with a coarse white carbonate sand containing many skeletal fragments. The only relief was an occasional oval-shaped depression with its major axis oriented along 060° parallel to the prevailing 0.2 knot current. These depressions were about 10 feet long, 5 feet wide, 6 inches deep, and appeared to be a result of current scour. After transitting about 1000 feet with the current, a series of ridges was encountered trending normal to the vehicle's course. These ridges, appearing to be sand waves, 3 to 8 feet high and 50 to 100 feet apart, had scour depressions on their northeast side. The crests of these ridges were covered with randomly-oriented rock slabs, likely manganese,(1.) approximately 12 inches thick and one to three feet wide. Flat sandy areas 30 to 50 feet across with small-scale current ripples were evident between the ridges. A thin mottled pavement of manganese was present beneath this coarse sand layer. DEEPSTAR was unable to obtain a sample from this very hard pavement. During the remainder of the transit, alternating areas of flat pavement covered with coarse sand and low ridges with manganese slabs on their crests were continuously encountered. Typical bottom photographs and a sketch of the bottom features are shown in Figures 11 to 14. The Westinghouse Ocean Bottom Scanning Sonar (OBSS), as shown in Figure 15, was towed across this area and the resulting record appears in Figure 16. Figure 17 is a photograph of a nodule obtained on this dive.

(1.) The terms manganese and manganese nodules as used in this report only denote that manganese is present in the rock samples and not that manganese is necessarily the predominant element.

FIGURE 11. MANGANESE BLOCK ABOUT 6 INCHES THICK

FIGURE 12. MANGANESE BLOCK ON THE BLAKE PLATEAU

FIGURE 13. VIEW OF LARGE SAND WAVE

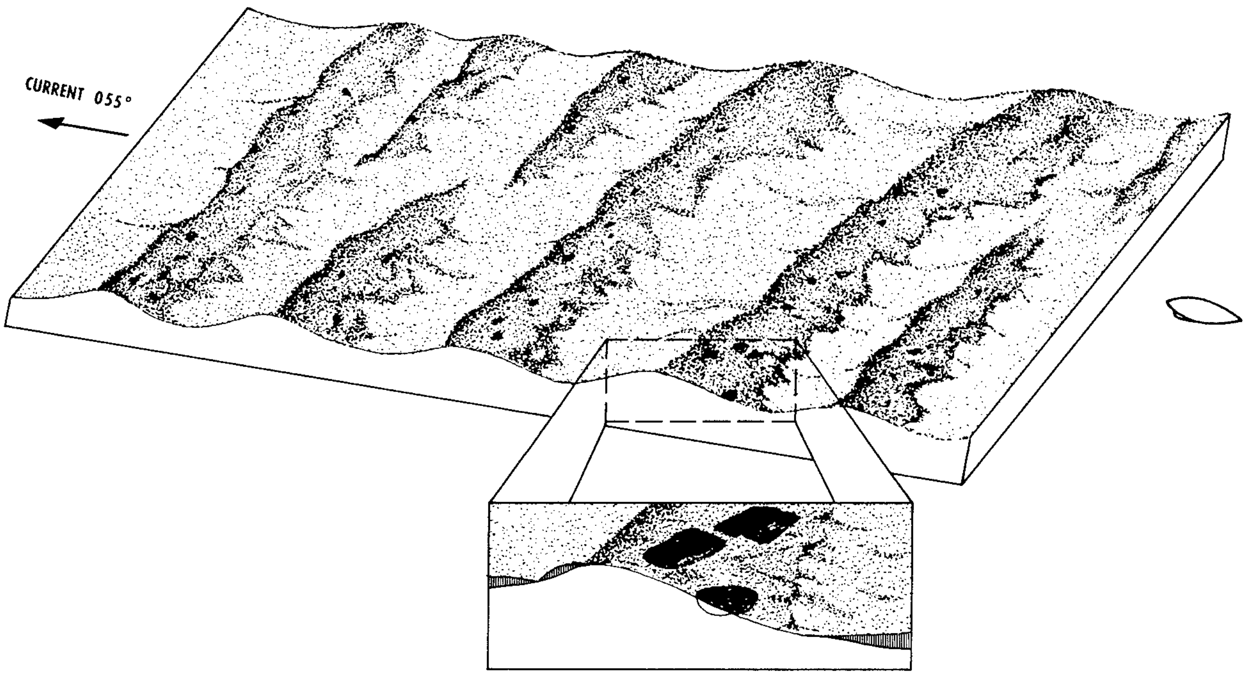


FIGURE 14. SKETCH OF BLAKE PLATEAU TOPOGRAPHY

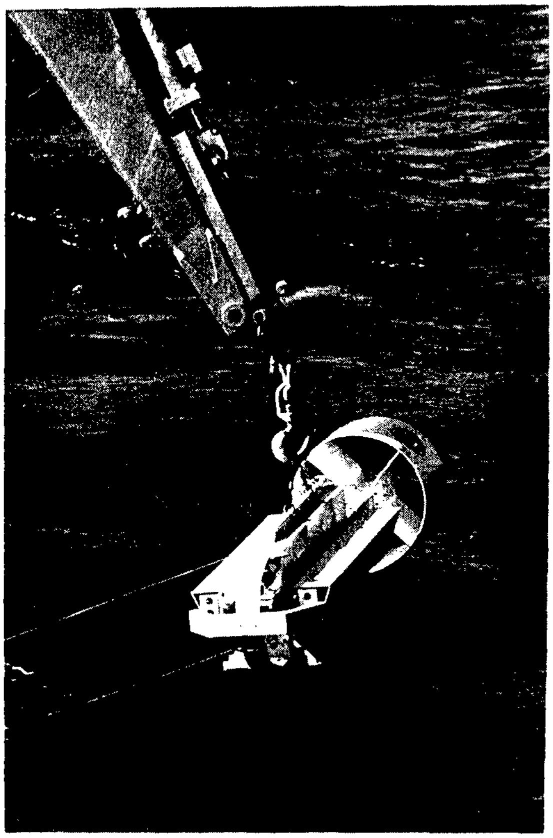


FIGURE 15. OCEAN BOTTOM SCANNING SONAR (OBSS)

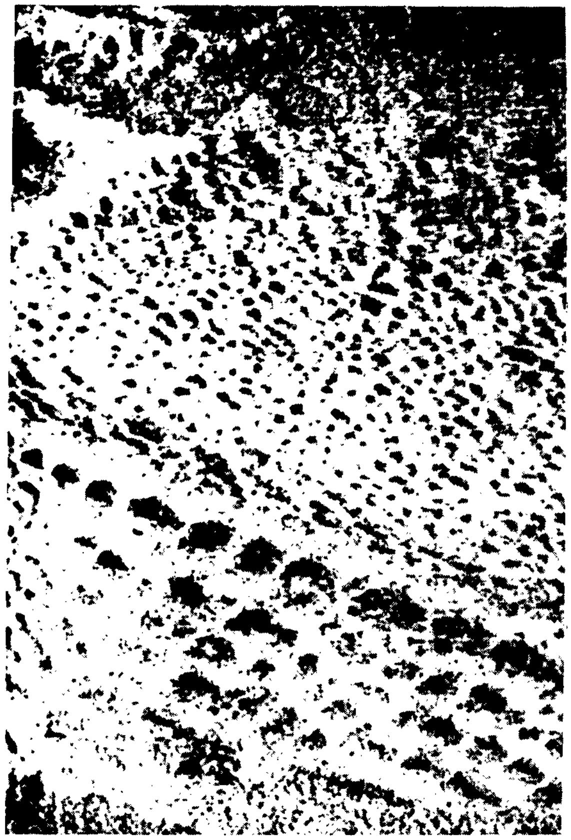


FIGURE 16. OBSS RECORD FROM THE BLAKE PLATEAU

FIGURE 17. NODULE; FRANCOLITE IS PREDOMINANT MINERAL WITH ARAGONITE PARTINGS

Physical properties. Water temperature near the bottom on this part of the Blake Plateau was 14.6°C. Current drift (0.2 - 0.4 knots) and current set (055° - 060°) were monitored throughout the transit. Visibility was 30 to 50 feet and not seriously affected by contact with the bottom due to the large grain size of the sediments. It was noted that the vehicle's manipulator could be seen in ambient light when on the bottom at a depth of 1500 feet.

Biology. The most significant biological occurrence was the presence of many gorgonians growing normal to the current on the crests of the ridges. A particularly large specimen (11 inches long) of an anglerfish (Chaunax sp.) was caught and held in the grab until DEEPSTAR was back aboard SEARCH TIDE. (Figure 18).

DIVE NO. 4

Location: Near Blake Escarpment (Figure 19)

	Descent	Ascent
Position:	31°21.3'N 77°17.1'W	31°21.4'N 77°18.0'W
Local time:	0947	1535
Water Depth:	650 feet	3600 feet

DIVE NO. 5

Location: Near Blake Escarpment (Figure 19)

Position:	31°20.5'N 77°17.2'W	31°21.0'N 77°18.0'W
Local time:	0919	1602
Water Depth:	3800 feet	3600 feet

Note: Since Dive No. 4, primarily a biology reconnaissance, and Dive

FIGURE 18. ANGLERFISH IN DEEPSTAR'S "ORANGE PEEL" SAMPLER

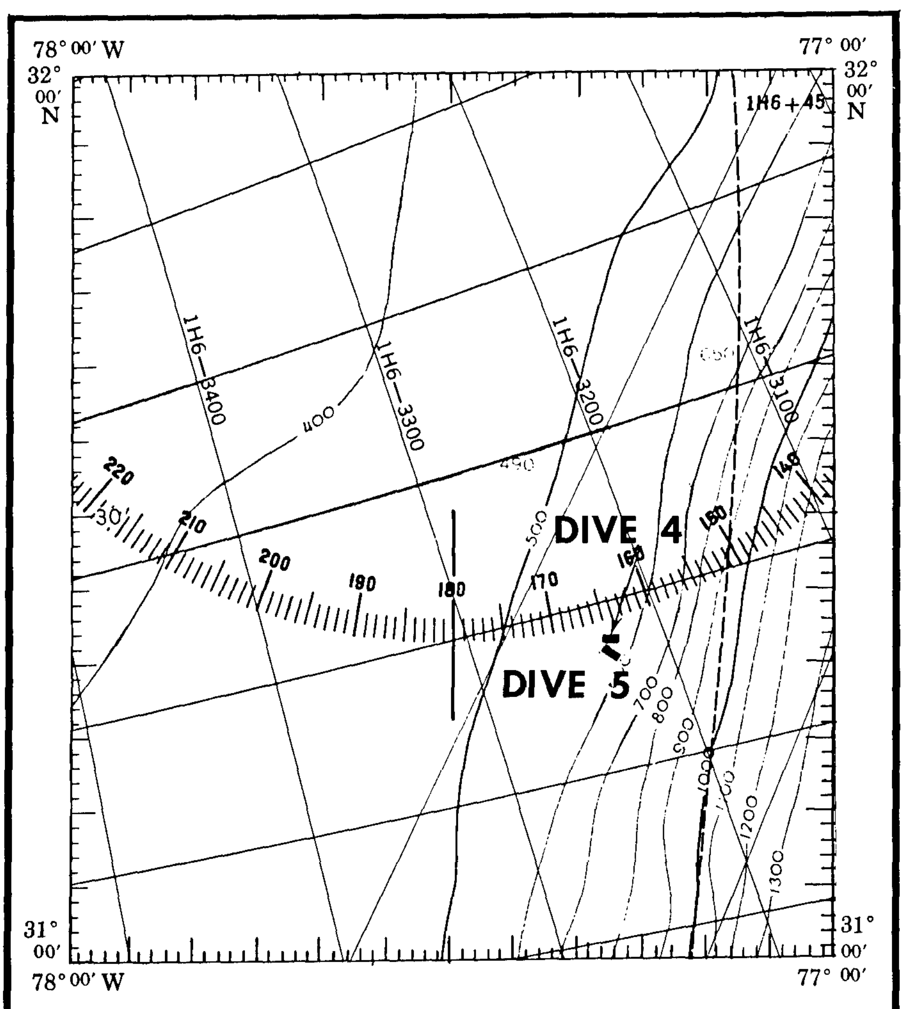


FIGURE 19. BATHYMETRY IN THE AREA OF DIVE NOS. 4 AND 5

No. 5, primarily a geology reconnaissance, were conducted in the same area, the results of the two dives have been combined below.

Geology. After reaching the bottom at 3800 feet, the vehicle began a transit on course 270° over a gently rolling bottom. A dark gravel, later analyzed as predominantly manganese, was concentrated on the crests of the small hills (Figure 20) while the troughs contained a coarse white sand.

Continuing along the track, the area became nearly covered with a crust of semi-lithified carbonate sand about 2 inches thick. It was undercut in several places, revealing the manganese-sand suite beneath it (Figure 21). Portions of this thin crust were irregular in shape but had smooth, rounded edges. A sample of this compact layer was obtained with the manipulator and later determined to have a calcite to quartz ratio of 5.5 to 1 but a major phase is still unidentified.

The manganese exposures on the tops of 1 to 2 foot ridges began to take on the appearance of a pavement as the bottom assumed a general 10 degree slope up to the west.

At a depth of 3750 feet, the bottom abruptly became rougher and the slope increased to about 20 degrees. Concentrations of gorgonians were seen growing on the large manganese slabs dominating the bottom. In this area the manganese pavement was broken into many large blocks 8 to 10 inches thick (Figures 22-24). This rugged area was bounded on the west by a talus slope of unconsolidated sand mixed with a high content of shell fragments. The bottom slope in this area was 30° to 40° up to the west.

FIGURE 20. SEDIMENT AND MANGANESE GRAVEL AT A DEPTH OF 3800 FEET

FIGURE 21. THE CALCITE–QUARTZ CRUST OVER MANGANESE-SAND SUITE

FIGURE 22. BROKEN MANGANESE PAVEMENT AT DEPTH OF 3750 FEET

FIGURE 23. CORAL (OR CORALLINA) GROWTH ON LARGE MANGANESE BOULDERS

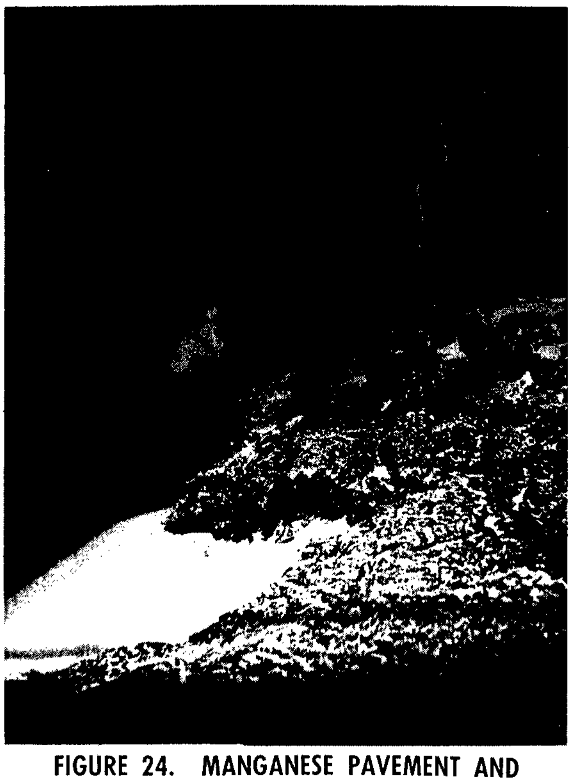


FIGURE 24. MANGANESE PAVEMENT AND SEDIMENT WITH HIGH SKELETAL CONTENT

The transit up this steep talus slope continued for an estimated 200 feet where a vertical wall was encountered. The exposed portion of the wall was black, about 20 feet high and had a sharp overhang. The top was flat for several feet and another slope of coarse, unconsolidated sand was encountered which ended at a second wall approximately five feet high.

After reaching the top of the second scarp at a depth of 3600 feet, the bottom had the same appearance as encountered at the beginning of the dive. It was generally flat with slight undulations and alternating 6 inch wide areas of coarse sand and manganese gravel oriented north-south. There was no evidence, however, of a compacted sand layer. The only significant relief encountered in this area was a single gully, 30 feet deep and 50 feet wide, oriented normal to DEEPSTAR's westerly course.

A sketch (Figure 25) shows the variety of bottom types while bottom samples are shown in Figure 26.

Physical properties. Near-bottom water temperature at the eastern end of the track was 4.3°C (depth - 3800 feet), and varied between 4.9 - 5.1°C near the track's western end (depth - 3600 feet). Currents experienced throughout the transit were weak (0 - 0.2 knots) and had a westerly set. Visibility was generally good and essentially unaffected by sediment stirring.

Biology. During descent and ascent on Dive No. 4 a faunal survey of the water column and observations of bottom life (for a period of about one hour) were made. As expected, a scarcity of animals was noted.

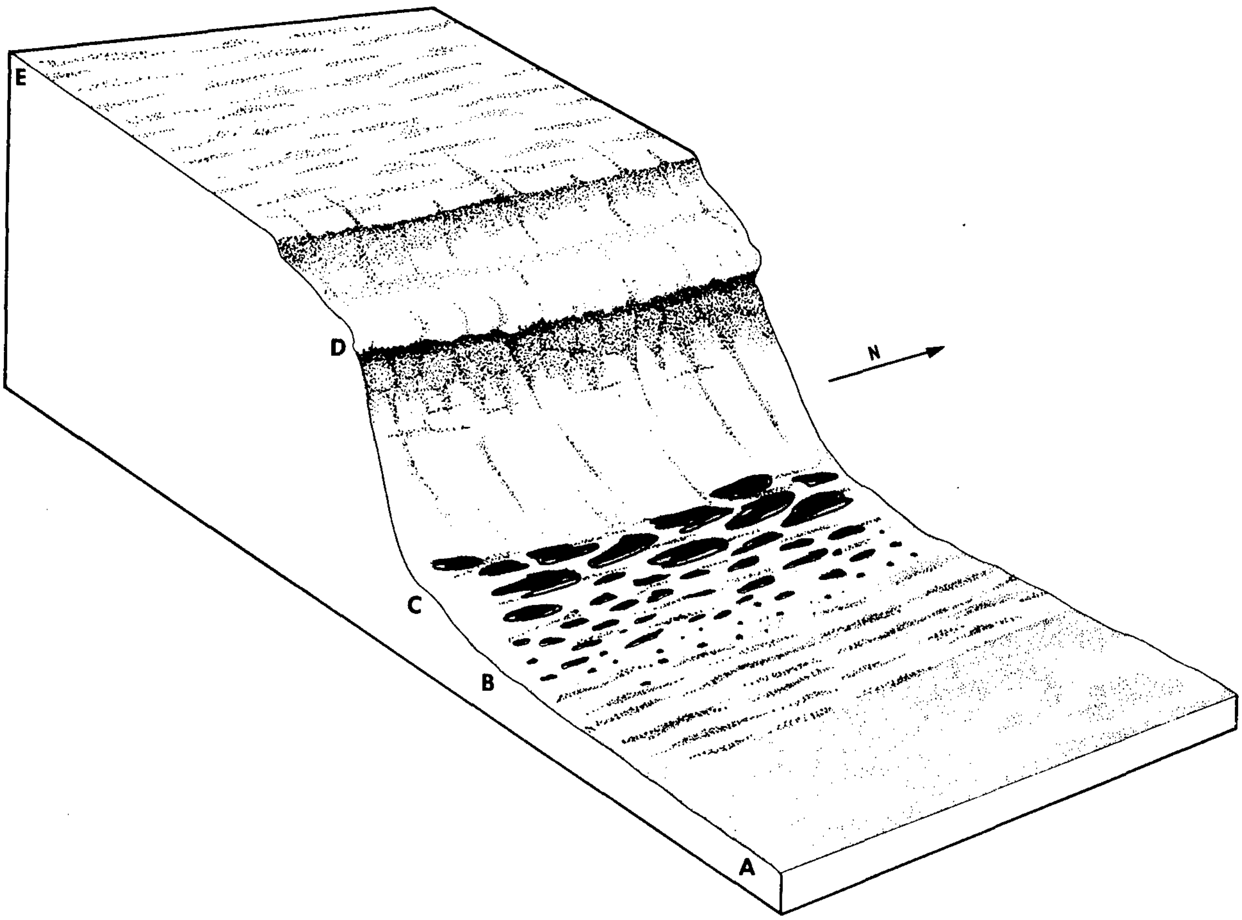


FIGURE 25. SKETCH OF PART OF BLAKE ESCARPMENT

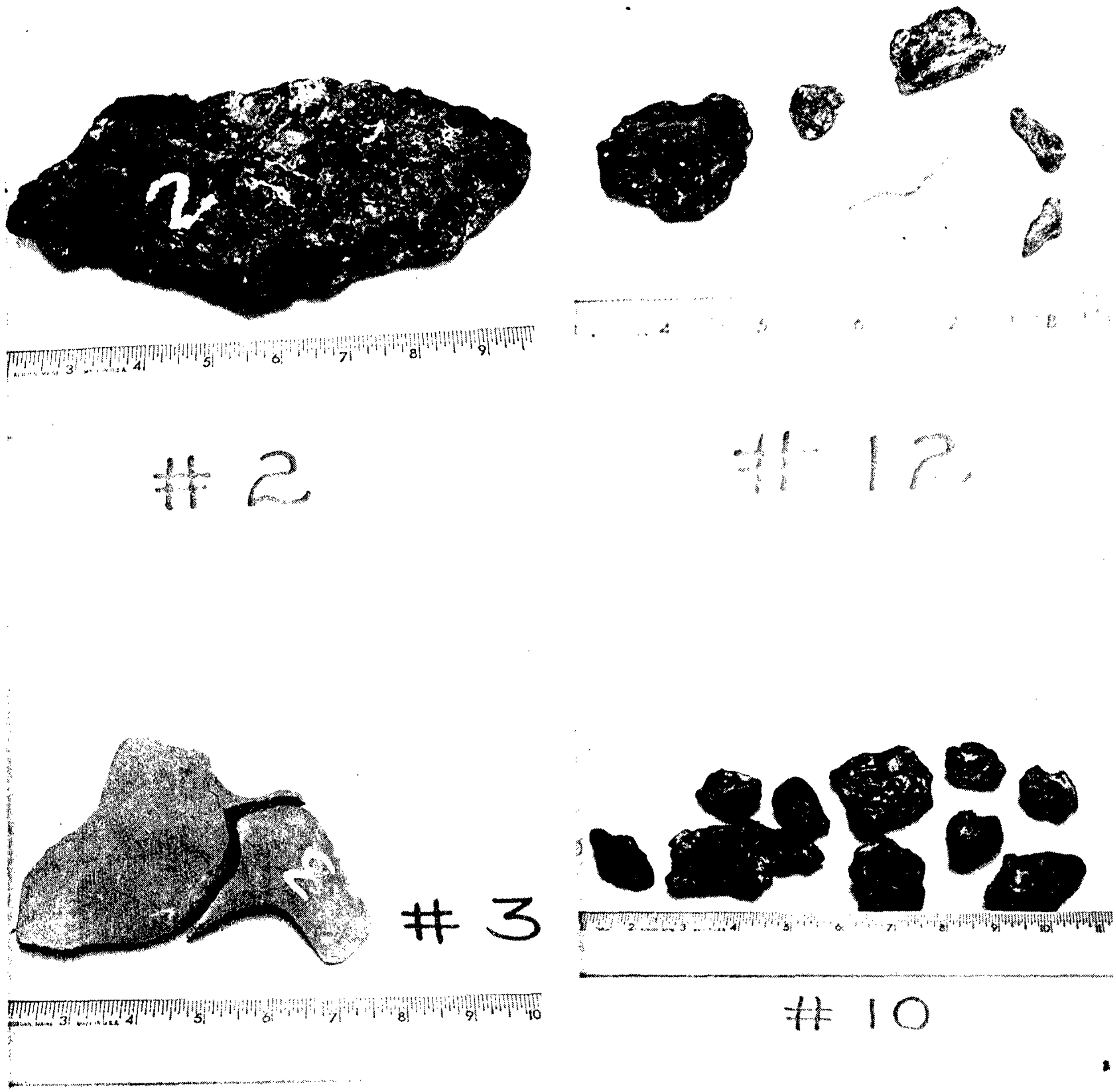


FIGURE 26. BOTTOM SAMPLES FROM DIVE 4 AND 5

No scattering layer was recorded on the depth recorder aboard SEARCH TIDE at the start of the dive, but layers were recorded at the time of the ascent. The main DSL appeared at approximately 230 to 350 fathoms and a weak secondary layer at 150 to 180 fathoms. There was no overall visual impression of organism layering on either the ascent or descent, but a few observations, particularly those made on the descent when the animals were more numerous, seem, in retrospect, to show some correlation with the DSL record. For example, the first fishes seen were at around 240 fathoms. They were small and silvery, possibly gonostomatids (bristlemouths). Above that level only invertebrates, mostly clear or with white body parts, had been seen. These were mostly arrow worms, a few large radiolarians, a few salps and, particularly between the depths of 140 to 205 fathoms, several chain-like colonies of siphonophores. At 290 fathoms and 315 fathoms, hatchetfish (sternoptychids) were seen. At about 465 fathoms and sporadically to the bottom, occasional long, slender silvery ribbon-like fish were seen, at most only about six inches long--possibly paralepidids or trichiurids. Occasional myctophids (lanternfish) and gonostomatids were seen from about the level of the scattering layer to the bottom. It proved impossible to identify any of the myctophids or most of the gonostomatids even to genus, so any species-specific depth preferences could not be detected. In general, most of the midwater fishes seemed to be oriented horizontally. Some, however, were head up or head down in position and virtually all were motionless until the vehicle moved closer. Fishes in particular, as well as invertebrates,

were extremely sparse during the ascent despite the indication of the presence of a prominent deep scattering layer at that time.

During approximately one hour of bottom observations, an estimated 50 to 75 near-bottom dwelling fish mostly 1 to 2 feet long were observed. Nearly all at this locality were slender and elongate. Most resembled notacanthids or halosaurids, but a single macrourid (rat tail) was seen oriented vertically, head down, about two feet above the bottom. Most of the fishes were oriented horizontally a short distance above the bottom and were either swimming slowly or were motionless. They did not seem particularly disturbed by the vehicle or lights and only darted off when the vehicle came close--at distances varying from about one foot to more than six feet.

Though much less conspicuous than the fishes, some invertebrates also were observed on the bottom. A particularly beautiful and slender anemone more than 18 inches high with tentacles extending to a diameter of three feet was observed. Near the end of the dive, however, large numbers of gorgonians were found on rocky outcrops bordering a small depression. A few solitary corals and deep sea sponges were seen on manganese nodules and examination around the edges of larger nodules revealed some numbers of small lobster-like crustaceans sitting in the entrances of burrows extending under the nodules.

A specimen of toadfish, probably Cottunculus sp., was caught with the manipulator and held until the vehicle was recovered.

DIVE NO. 6

Location: Cay Sal (Figure 27)

	Descent	Ascent
Position:	23°58.5N 80°30.0W	23°58.2N 80°28.0W
Local Time:	1722	2343
Water Depth:	2850 feet	950 feet

Geology. Three distinct topographic areas were observed during the dive transit upslope normal to the contours. The first area, between depths of 2850 and 2750 feet, was covered with a coarse, light-colored, well-compacted sand. The gently rolling bottom had an estimated slope of 5°. These undulations strongly resembled low, rounded sand waves. The only other major feature encountered in the area was a single (scour?) channel about 40 feet wide, 10 feet deep, and trending NE-SW normal to DEEPSTAR's upslope course. The floor of the channel was flat and covered with low, short-period ripple marks of coarse sand.

Between depths of 2750-2300 feet the bottom lost its gentle appearance and was characterized by more abrupt changes. Sharp-crested ridges often resembling barchan-type dunes were in evidence. Sediment streamed over the smooth dune surfaces and was deposited on the steep down-current sides. Between the dunes the bottom was rippled with short steep ripples (Figure 28). Several narrow but deep scour channels were encountered and changes in the orientation and characteristics of ripple marks and current activity were rapid. Boulders and calcarenite outcrops became numerous and coincided with increased evidence of scouring.

The third topographic area occurred at depths between 2300 feet and 950 feet, the minimum depth at which DEEPSTAR was in contact with the

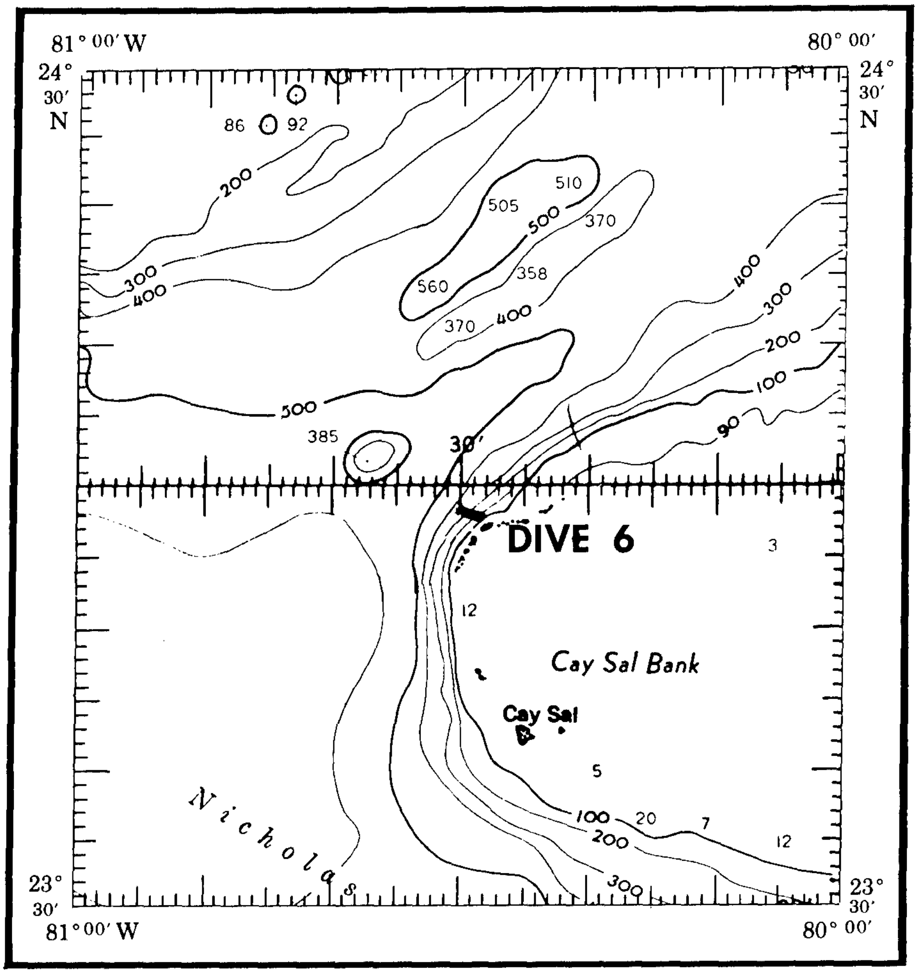


FIGURE 27. BATHYMETRY IN THE AREA OF DIVE NO. 6

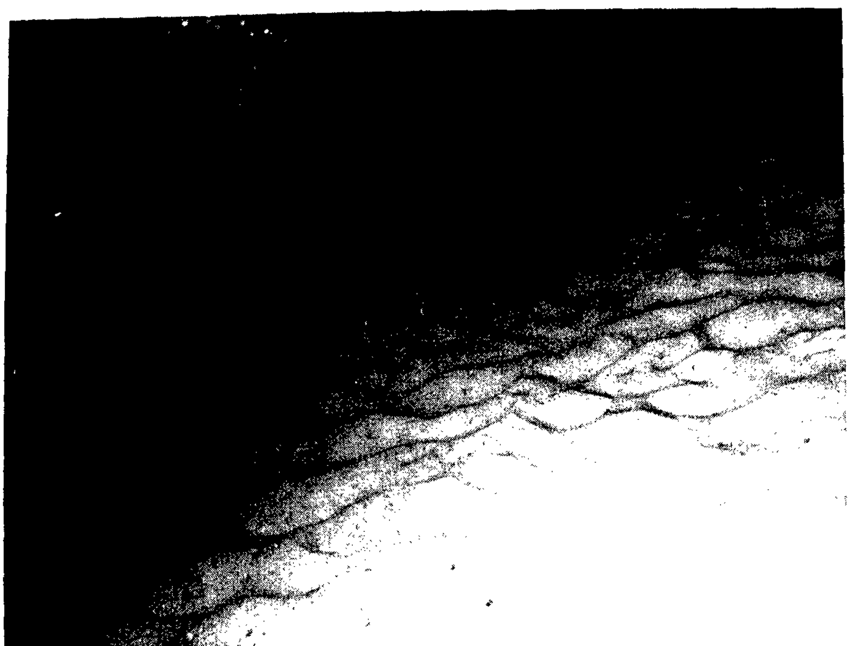


FIGURE 28. RIPPLE MARKS AT A DEPTH OF 2500 FEET

bottom. The bottom slope increased abruptly from about 10° to 30°. The ridge features disappeared and the lack of unconsolidated sediment was notable. However, scour channels were still present and their NE-SW orientation persisted.

The bottom was generally scoured but had intermittent low-rippled areas. In the (current?) smoothed areas, scour depressions and sediment shadows were seen on the upstream and downstream sides, respectively, of sessile fauna (Figure 29).

At about 1000 feet large sediment-covered boulders were encountered. Figure 30 shows DEEPSTAR's mechanical arm attempting to sample a growth of black coral (Order Antipatharia) attached to one of these boulders.

Figure 31 shows a rock sample obtained on this dive and a sketch of the bottom topography appears in Figure 32.

Physical properties. This is a very dynamic area because of its proximity to the Florida Current. When measurable, bottom currents throughout the upslope transit had a 030° set, essentially parallel to the depth contours. While the presence of ripple marks, dunes, scour channels, and sand flows was noted throughout the dive, a current drift of less than 0.2 knots was experienced by DEEPSTAR during the major part of the dive. The only exceptions were at depths near 1750 feet and 1550 feet where drifts of 0.5 knots were encountered. Turbidity accompanied this increase in current speed and reduced visibility to about 20 feet at these depths.

Since these two strong current layers were the only ones of a magnitude capable of forming the bottom features observed, it appears that these currents must be regularly-occurring but meandering flows.

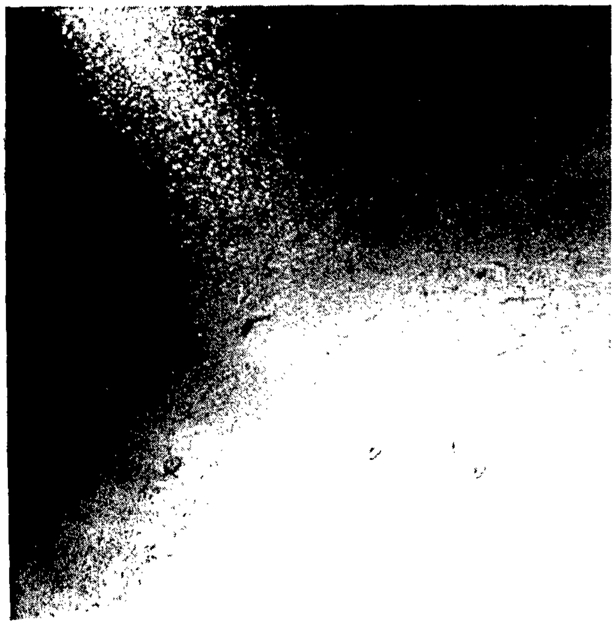


FIGURE 29. EXAMPLE OF SCOUR DEPRESSIONS AND SEDIMENT SHADOWS

FIGURE 30. LARGE CALCARENITE BOULDER AT A DEPTH OF 1000 FEET

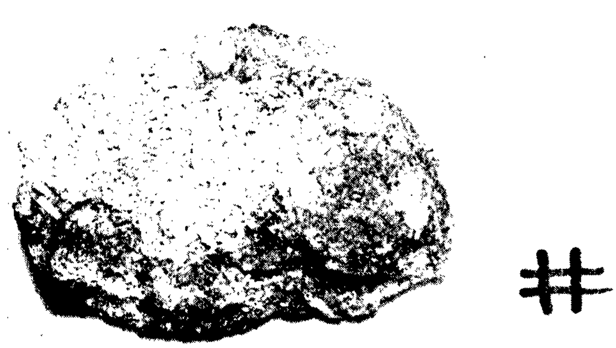
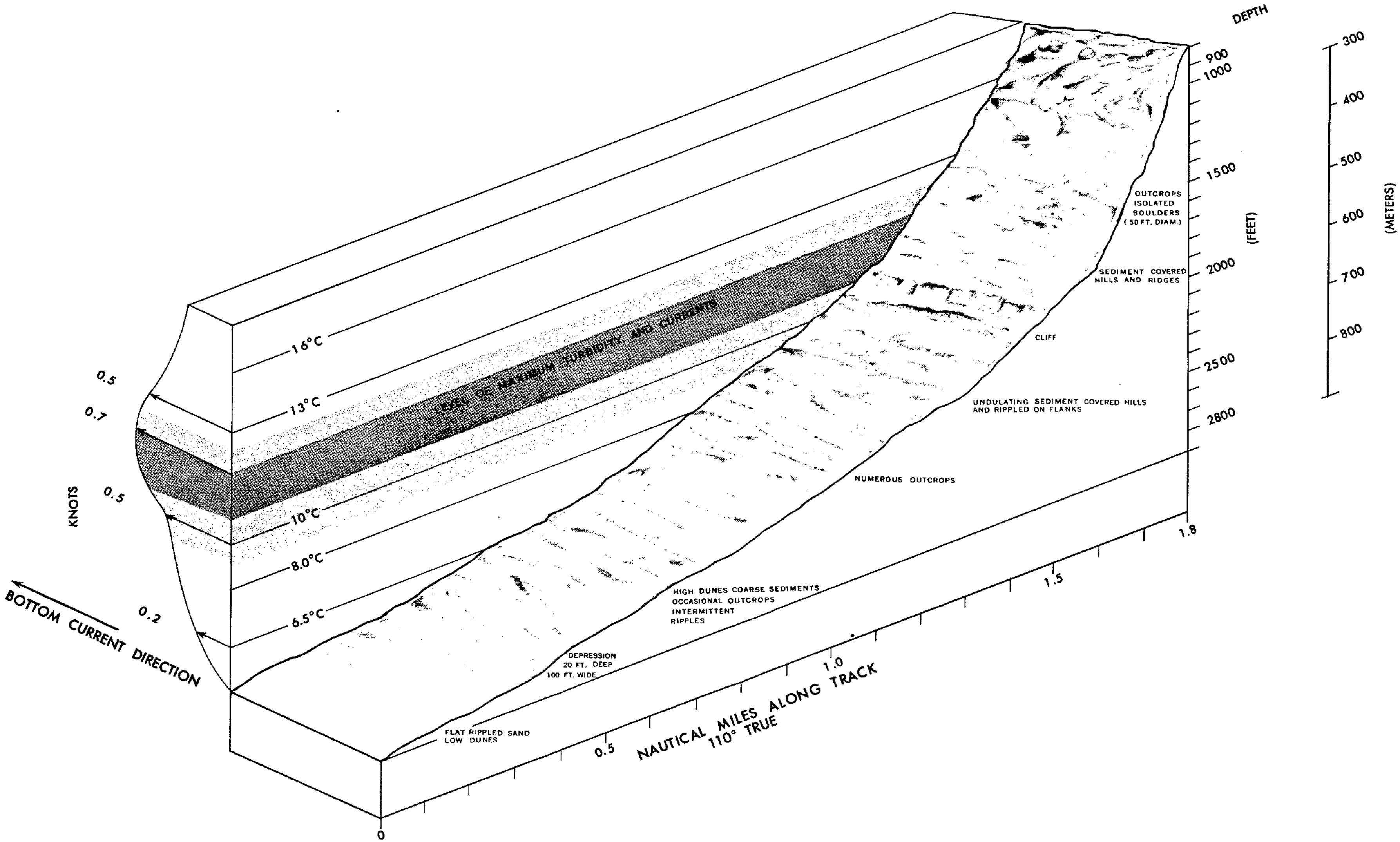


FIGURE 31. BOTTOM SAMPLE OF DIVE NO. 6



BOTTOM TOPOGRAPHY AND BOTTOM CURRENT PROFILE CAY SAL BANK, DEEPSTAR 4000 SURVEY NOV. 1967

FIGURE 32. SKETCH OF BOTTOM FEATURES NEAR CAY SAL

Near-bottom water temperatures were 6.47°C at 2850 feet; 6.53°C at 2750 feet; 8.50°C at 2300 feet; and 16.22°C at 1150 feet.

Biology. A sparse myctophid population was sighted during descent and during the bottom transit between depths of 1000 and 1500 feet. Gorgonian corals, oriented normal to the current, were much in evidence on the slope at depths from 2750 to 2300 feet. A spiny lobster (Figure 33) also was seen in this area.

DIVE NO. 7

Location: Cozumel (Figure 34)

	Descent	Ascent
Position:	20°15'N 86°52'W	20°18'N 86°54'W
Local time:	1514	2057
Water Depth:	3350 feet	900 feet

Geology. After bottoming on a nearly featureless area of light tan silt (Figure 35), DEEPSTAR began to run on a course of 315° and encountered two depressions trending NE-SW.

At the westerly limit of the second depression (depth, 3000 feet) an escarpment about 150 feet high was encountered. The escarpment (Figure 36) was black and small active sand streams were running down its face which produced a slight talus pile at the base. The outcrop had a strike of 060° and was nearly vertical. The top was flat and covered with fine unconsolidated sediment. About 20 feet back from the rim of this large outcrop was a smaller outcrop about 10 feet high; both appeared to be limestone.

FIGURE 33. APPARENTLY-BLIND SPINY LOBSTER AT A DEPTH OF 2500 FEET

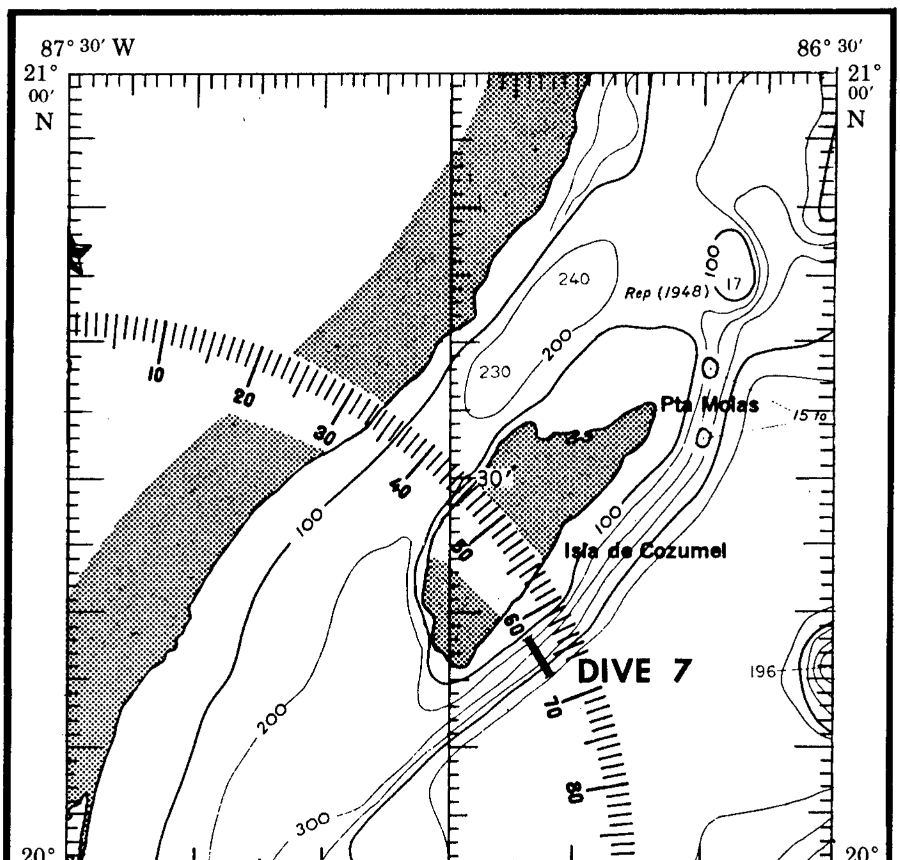


FIGURE 34. BATHYMETRY IN THE AREA OF DIVE NO. 7

FIGURE 35. NEARLY FLAT, SILTY BOTTOM

FIGURE 36. NEAR-VERTICAL ESCARPMENT WITH SMALL SAND STREAMS

The bottom above the outcrop consisted of a fine sediment up to a depth of 2500 feet where another outcrop, also apparently limestone, was encountered (Figure 37). This outcrop was about 30 feet high, mantled with fine sediment, and extended about 200 feet in a northeasterly direction. The slope above this outcrop was about 10 degrees up to the west, generally smooth with unconsolidated sediments and no ripple marks.

Steeper (20°) slopes were encountered at about 1900 feet depth. Small outcrops or boulders (Figure 38) showing evidence of current scour around their bases were seen at about the same depth.

At a depth of about 1700 feet six-inch ledges were seen and appeared to have manganese staining or replacement on them. As DEEPSTAR proceeded on course 315° the bottom character gradually changed to a coarser sand with small low outcrops oriented in random directions.

An outcrop 15 feet high was observed at a depth of 1550 feet. It appeared to be well-rounded and closely resembled a weathered reef (Figure 39). Above this outcrop approximately 25 percent of the 30 degree slope was covered with manganese nodules - the remainder by coarse sand. This area graded into a dark pavement with many basket sponges in evidence (Figure 40).

At 1300 feet the pavement gave way to a sandy slope and a series of long jagged reef-like ridges partially buried by coarse sediments (Figure 41). These hard rock ridges were about 100 feet apart, their orientation being nearly normal to our heading of 315°. The coarse sand between the ridges exhibited NE-SW striations and current scouring was evident.

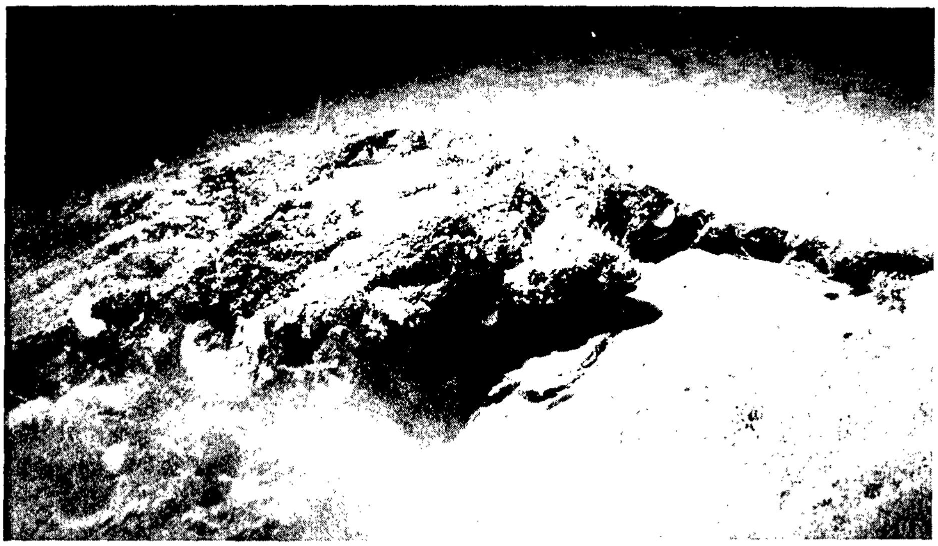


FIGURE 37. LIMESTONE (?) OUTCROP AT A DEPTH OF 2500 FEET

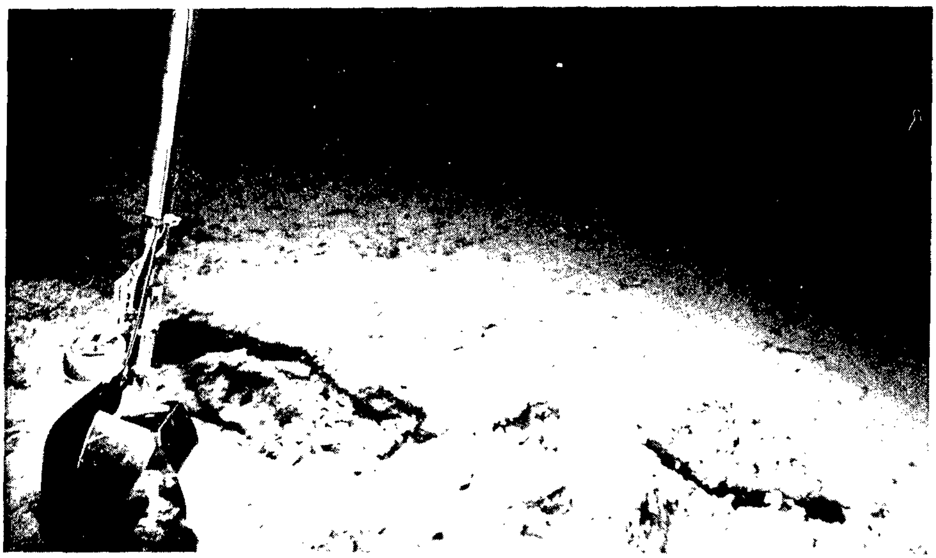


FIGURE 38. OUTCROP OR BOULDER WITH SOME EVIDENCE OF SCOURING

FIGURE 39. WELL-ROUNDED, WEATHERED REEF–1550 FEET DEEP

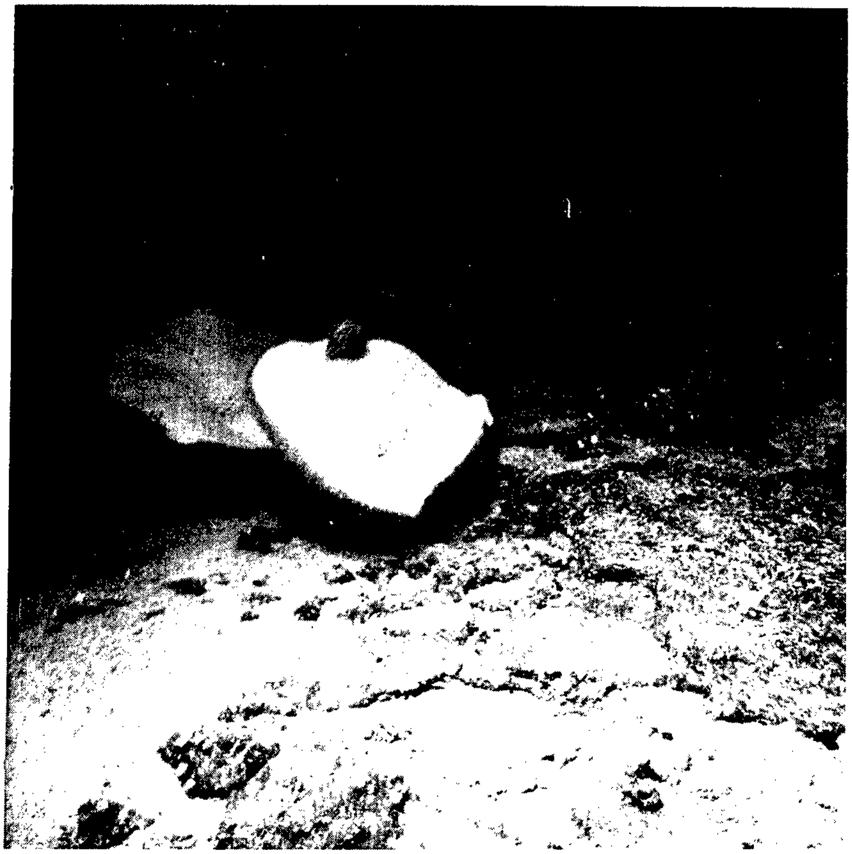


FIGURE 40. BASKET SPONGES GROWING ON MANGANESE PAVEMENT

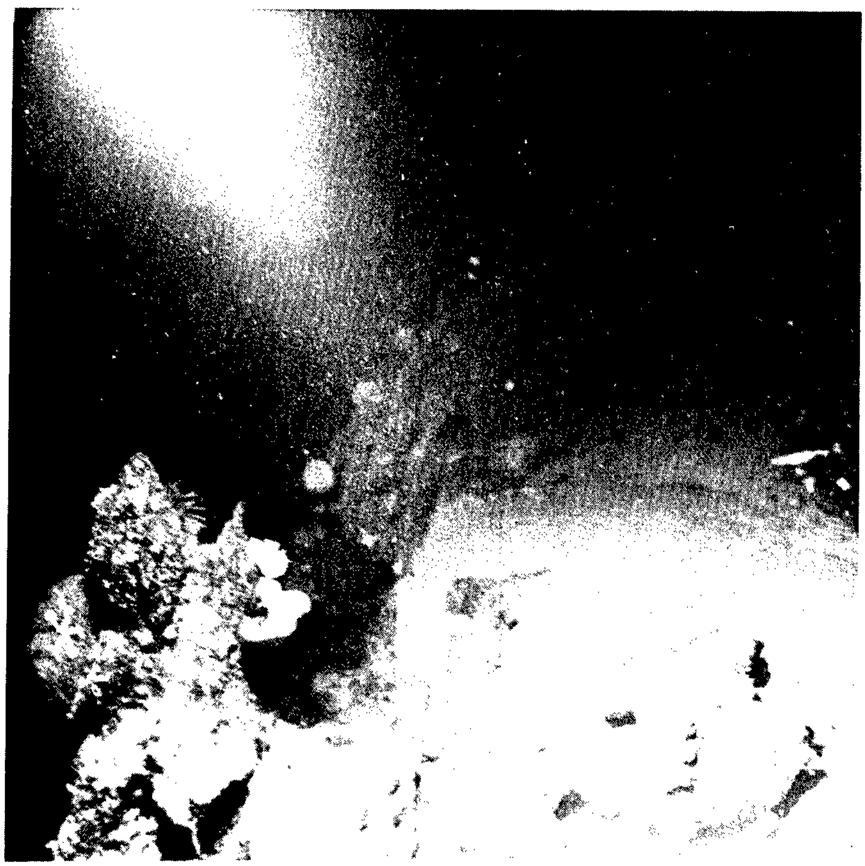


FIGURE 41. ONE OF THE REEF-LIKE RIDGES ENCOUNTERED

Figure 42 is a sketch of the area transited by DEEPSTAR; Figure 43 is a bathymetric profile from SEARCH TIDE's echo-sounder, and Figure 44 is the OBSS record along the same track. Two rock samples from this dive are shown in Figure 45.

Physical Properties. During the transit DEEPSTAR experienced a weak current setting SSW, with a 0-0.1 knot drift between depths of 3350 feet and 1400 feet. After passing 1400 feet a current setting NNE, was encountered. The drift of this current increased rapidly upslope reaching almost 2 knots at a depth of 900 feet. This strong current was accompanied by reduced visibility and made it impossible to control DEEPSTAR. The dive was aborted and the vehicle was forced to surface.

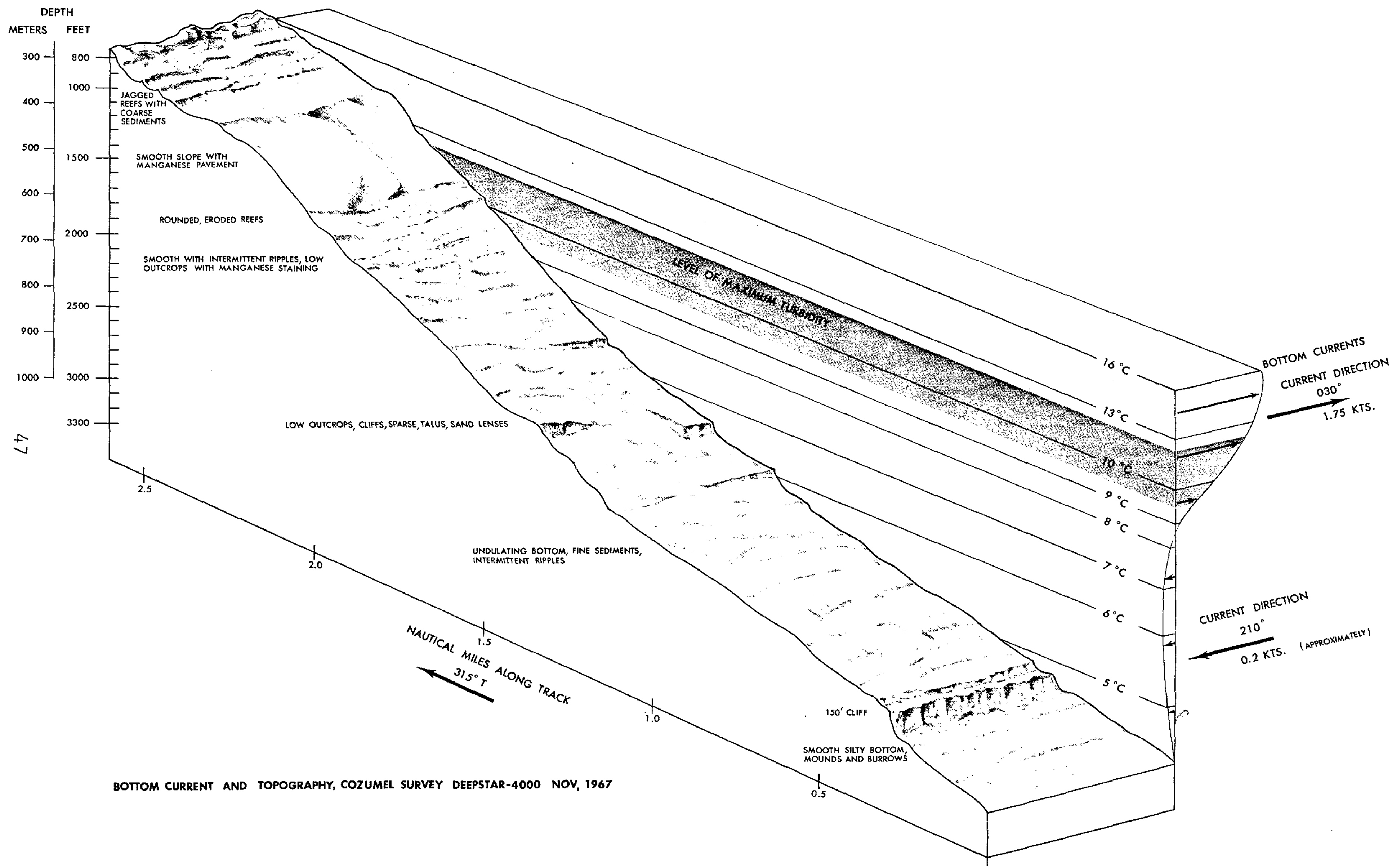
Bottom temperatures monitored during transit were 4.92°C at 3300 feet; 6.02°C at 2500 feet; 7.00°C at 1900 feet; 10.90°C at 1500 feet; and 16.46°C at 900 feet.

Biology. During transit upslope the most significant biological observations included sightings of fairly dense schools of hatchet-fish (Sternoptychid) within 10 feet of the bottom between depths of 2400-2000 feet, siliceous sponges (Class Hexactinellida) at 1700 feet, basket sponges at 1400 feet, and gorgonian corals at 1200 feet.

DIVE NO. 8

Location: Misteriosa Bank (Figure 46)

	Descent	Ascent
Position:	18°53'N 83°57'W	18°52'N 83°56'W
Local time:	1144	1508
Water Depth:	3800 feet	2200 feet



BOTTOM CURRENT AND TOPOGRAPHY, COZUMEL SURVEY DEEPSTAR-4000 NOV, 1967

FIGURE 42. SKETCH OF MAJOR BOTTOM FEATURES NEAR ISLA DE COZUMEL

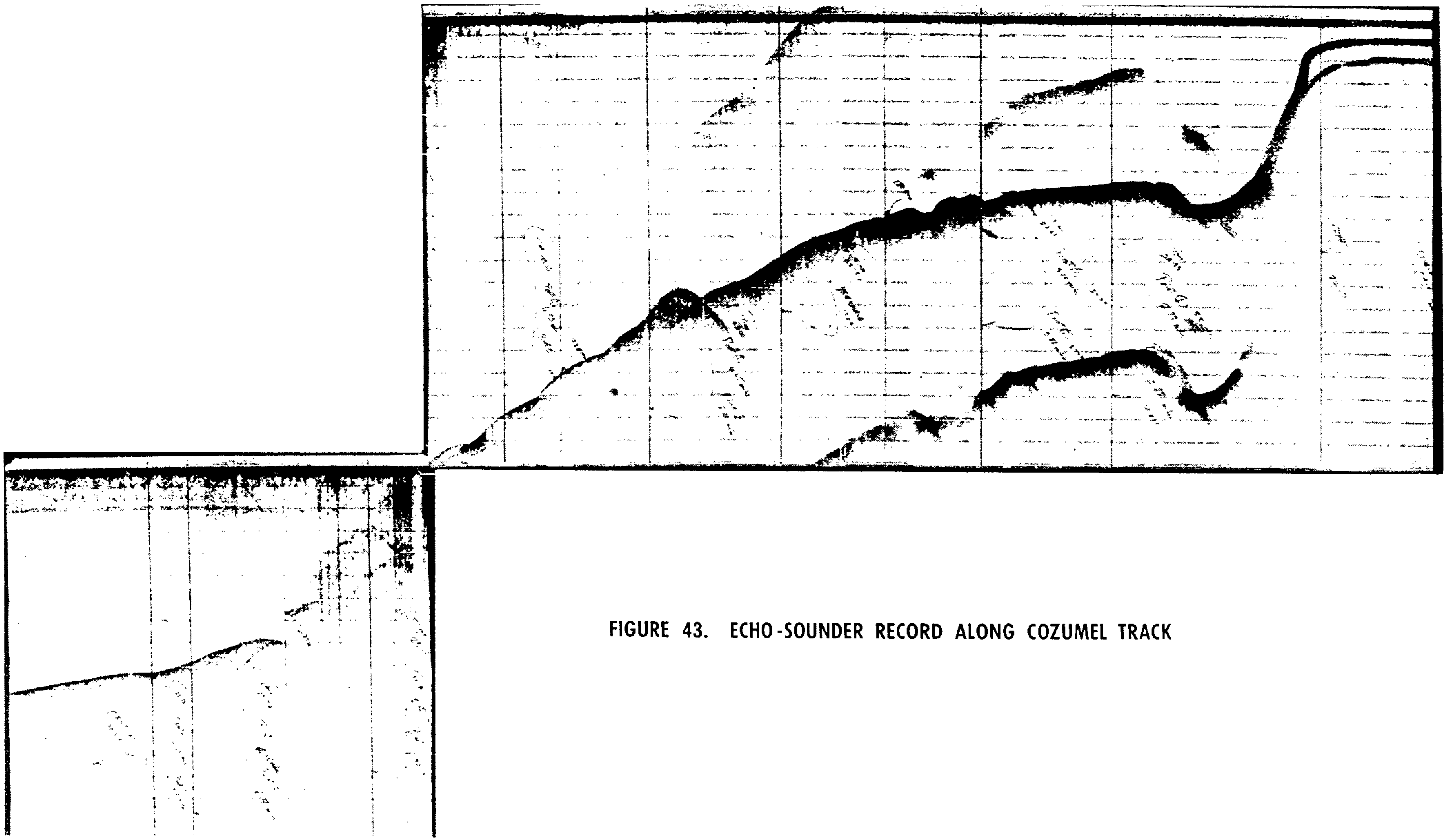


FIGURE 43. ECHO-SOUNDER RECORD ALONG COZUMEL TRACK

FIGURE 44. OBSS RECORD AT COZUMEL

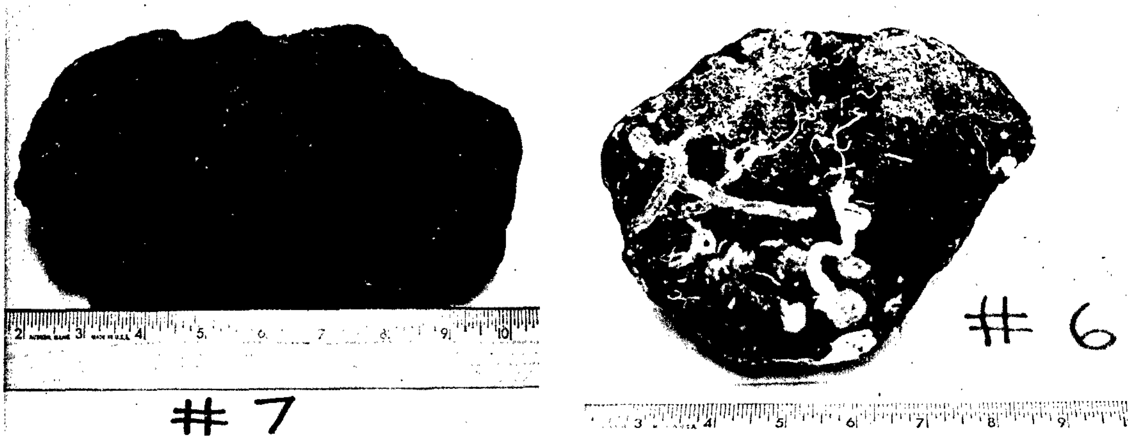


FIGURE 45. BOTTOM SAMPLES FROM COZUMEL

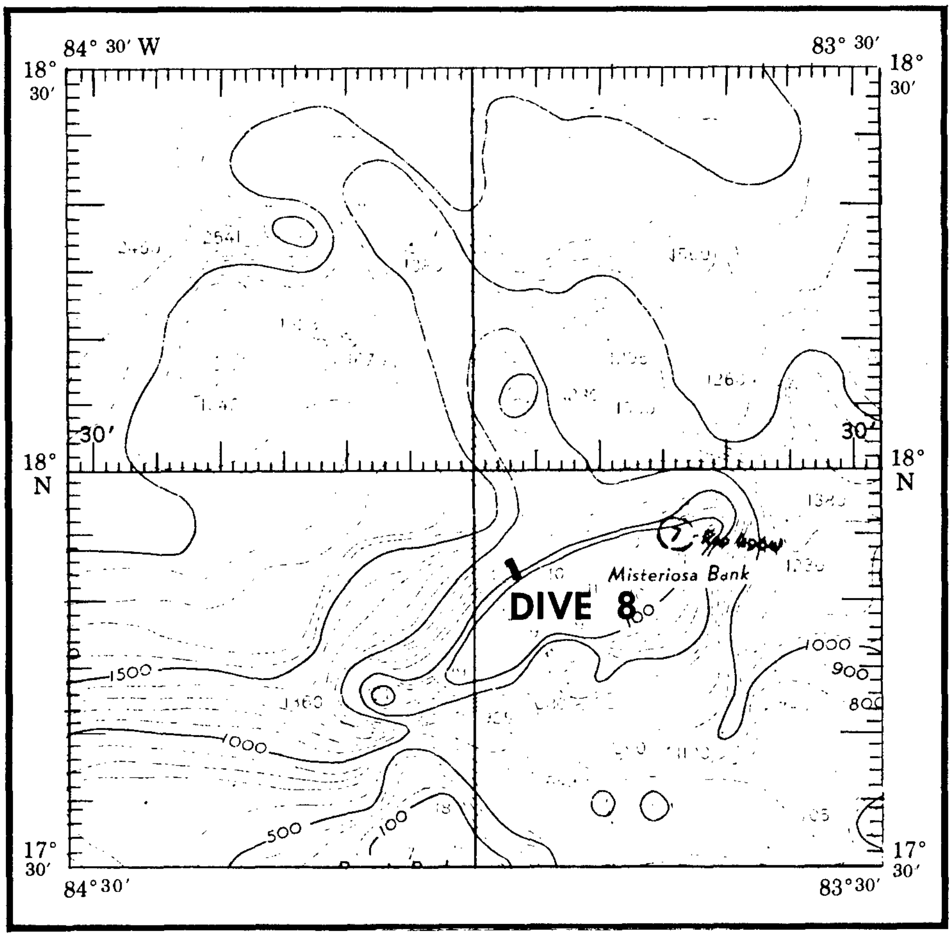


FIGURE 46. BATHYMETRY IN THE AREA OF DIVE NO. 8

Geology. DEEPSTAR reached a light tan, fine-grained sand bottom at a depth of 3800 feet. Small grooves, burrows and mounds indicated the presence of bottom organisms. It appeared that the first bottom contact was on a local feature with a slope of about 15 degrees. An erosional channel could be seen a few yards away that revealed undercutting and consequent slumping of a thin six inch veneer of consolidated material, possibly calcarenite. The channel was about eight feet wide.

On course 150°, DEEPSTAR commenced an upslope transit. It was soon determined that the accumulated sediment was a thin veneer over solid material, possibly limestone. The general slope appeared to be 20° to 30° up to the south.

Several boulders, up to eight feet across, were encountered. They appeared to be a carbonate material and may have been fractured remnants that rolled downslope (Figures 47 and 48).

At a depth of 3600 feet the slope increased to about 40°. The extremely hard bottom exhibited little sediment accumulation. Gentle undulations in an otherwise smooth bottom were noted. A ridge was encountered and followed upslope. The ridge was very narrow, fell away rapidly to either side and ended at the sheer face of an outcrop. Thereafter, from a depth of 3500 feet to 2200 feet, the topography was comprised of very steep sediment slopes alternating with large near-vertical rock scarps (Figure 49).

On several occasions the vehicle followed narrow incising canyons or fractures which were flanked by sheer rock walls. The bottom of these

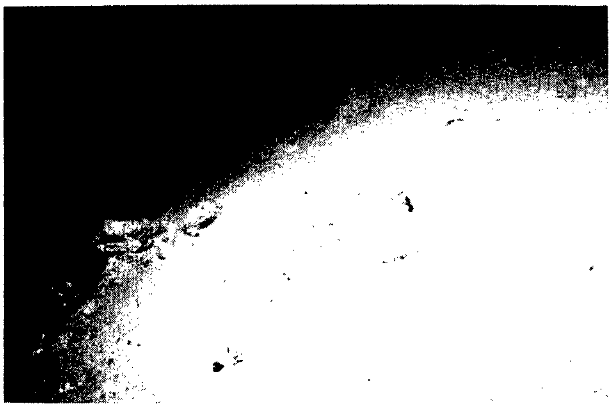


FIGURE 47. CARBONATE BOULDERS AT A DEPTH OF 3700 FEET

FIGURE 48. CARBONATE BOULDER IN A LOCAL DEPRESSION

FIGURE 49. NEAR-VERTICAL ROCK SCARP AT A DEPTH OF 2400 FEET

canyons was usually covered with a thin layer of sediment. Evidence of both small- and large-scale downslope sediment movement was present during the remainder of the bottom transit.

The echo-sounder record from SEARCH TIDE over this very steep area is shown in Figure 50.

Physical Properties. A current with a northerly set (downslope) was experienced throughout the bottom transit. Below a depth of 2600 feet this current was weak (<0.2 knots) and did not hinder DEEPSTAR's upslope progress. At a depth of 2550 feet, however, current drift showed a marked increase and the vehicle was swept from the top of one of the vertical exposures. This happened a second time and DEEPSTAR was swept into a spin. After much difficulty returning to the steeply sloping bottom the dive was aborted at a depth of 2200 feet.

Water temperature was 4.75°C at 3500 feet; 5.36°C at 3000 feet; and 7.08°C at 2400 feet.

Biology. The presence of bottom dwelling organisms was evidenced by the sightings during the dive of worm burrows, small mounds, depressions, and occasional halosaurids, crabs, shrimp, and anemones attached to isolated boulders. These sightings are typical for deep dives and the absence rather than the presence of these animals would be more notable. Hence, no animals were observed whose presence was unique or unexpected.

DIVE NO. 9

Location: Rosalind Bank (Figure 51).

	Descent	Ascent
Position:	16°00'N 80°37'W	16°01'N 80°35'W

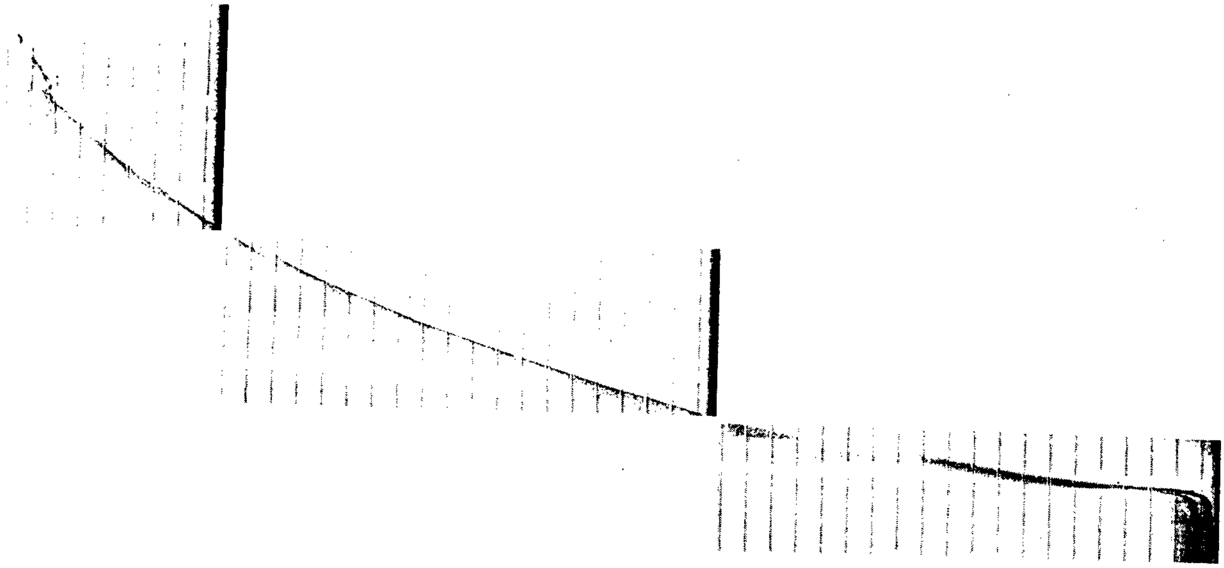


FIGURE 50. ECHO-SOUNDER RECORD FROM MISTERIOSA BANK

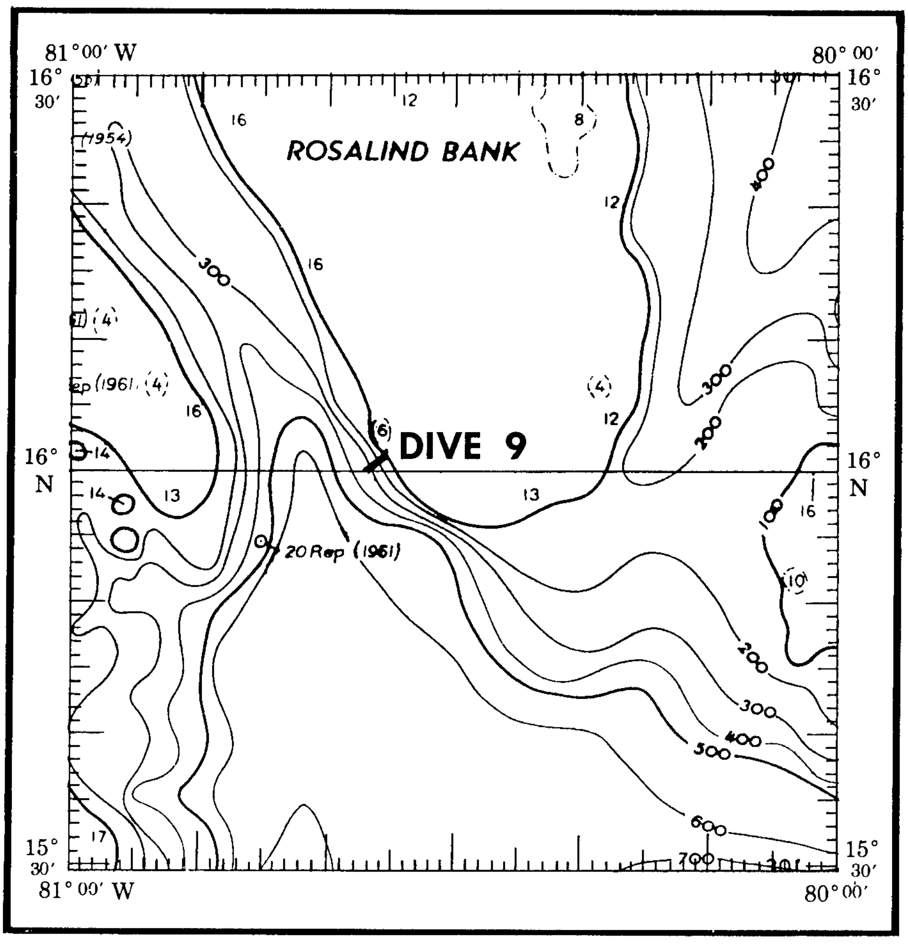


FIGURE 51. BATHYMETRY IN THE AREA OF DIVE NO. 9

	Descent	Ascent
Local time:	1624	2101
Water Depth:	1850 feet	110 feet

Geology. At the dive site, the bottom was flat with light-colored silty unconsolidated sediments and low animal mounds.

At the beginning of the dive transit, the course was 070°, and normal to the contours. At 1800 feet, low limestone outcrops with some manganese replacement were seen with ripple marks in the depressions between the outcrops. Alternating outcrops and rippled depressions were characteristic of the topography up to 1700 feet depth (Figure 52).

The slope gradually increased above that depth. Larger sand waves or small dunes were dominant, and suspended sediment was observed moving over the bottom.

At 1600 feet low, lightly weathered coral outcrops with minor manganese replacement were encountered.

At a depth of 1500 feet the bottom was again characterized by active movement of sediment. The dunes, sand waves and the ripple marks were larger and closely resembled the bottom seen at Cay Sal (Dive 6). Some large dunes (>40 feet high) were encountered at this level. Between depths of 1400 and 800 feet the bottom was fairly well scoured and slopes of 20 to 40 degrees were observed.

At 750 feet DEEPSTAR encountered a vertical outcrop that proved to be the base of the marginal escarpment (Figures 53 and 54). The face of the outcrop was covered with various corals and many caves and large overhangs were sighted during subsequent ascent along this feature to its top at a depth of 110 feet.

Four bottom samples collected on this dive are shown in Figure 55.

FIGURE 52. LIMESTONE OUTCROP AND ADJACENT SAND RIPPLES

MARGINAL ESCARPMENT PHOTOGRAPHED THROUGH FOGGED PORT
FIGURE 53.

FIGURE 54. SKETCH OF MARGINAL ESCARPMENT AT ROSALIND BANK

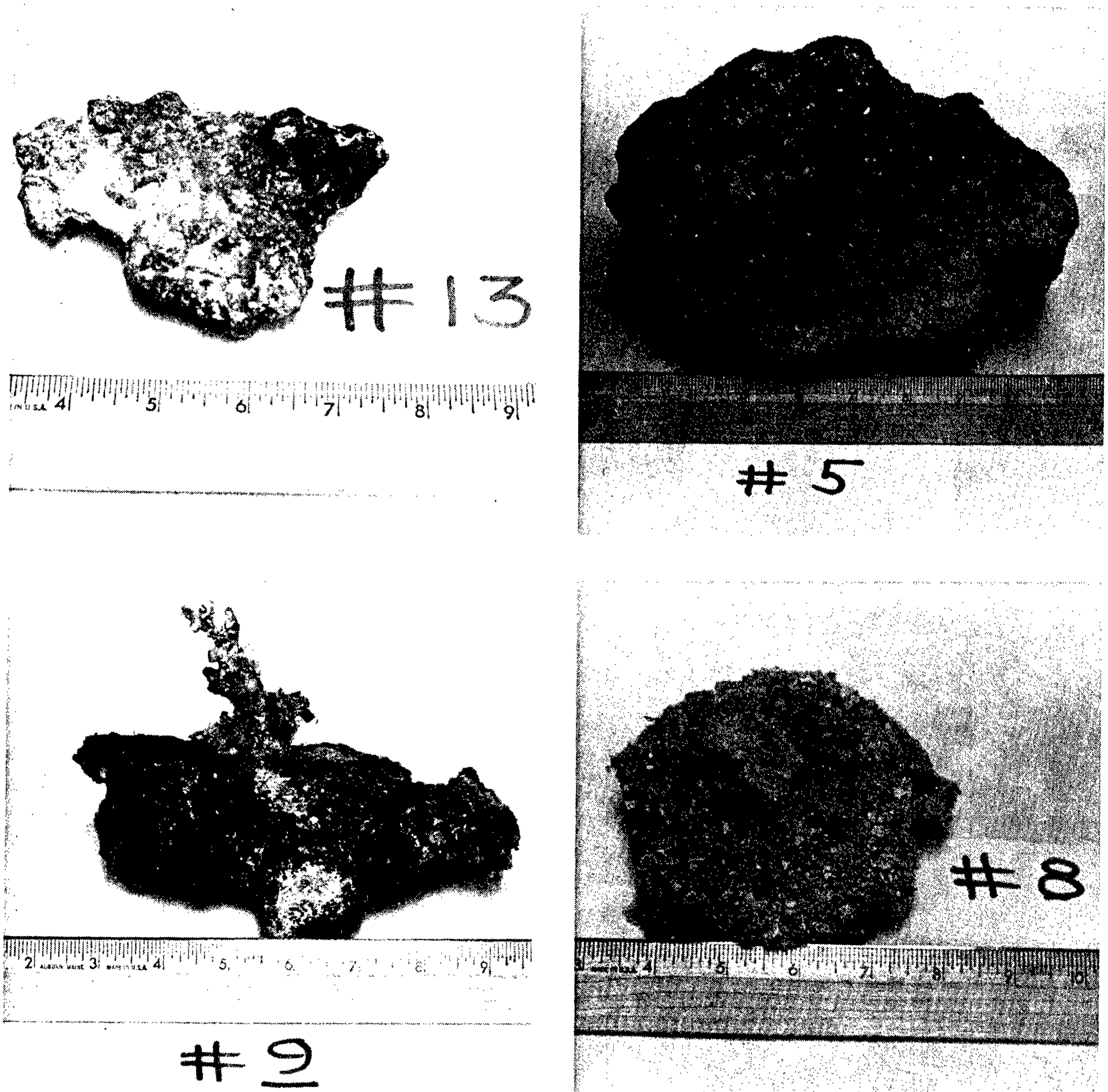


FIGURE 55. BOTTOM SAMPLES FROM ROSALIND BANK

Physical Properties. Significant currents were encountered during a large part of the bottom transit. Between depths of 1850 and 1600 feet current speed was about 0.25 knots and direction 300°. While set was nearly constant (300°), drift increased rapidly from 0.25 knots at 1600 feet to 1.5 knots at 1250 feet then diminished to 0.2 knots at 800 feet. The core of a second relatively high velocity layer (1 knot) was encountered at a depth of 480 feet.

Typical bottom temperatures were 7.75°C at a depth of 1850 feet; 9.15°C at 1600 feet; 11.66°C at 1350 feet; 13.89°C at 1100 feet; 17.51°C at 900 feet; 19.10°C at 800 feet. Although the temperature probe was not calibrated for temperatures above 20°C, effects of a strong thermocline were noted at 750 feet depth.

Biology. Large leopard sharks (*Triakis semifasciatum*) were noted as they darted by the vehicle throughout the descent and bottom transit. At depths near 1600 feet the large number and variety of marine animals was notable.

DIVE NO. 10

Location: Roncador Cay (Figure 56).

	Descent	Ascent
Position:	13°35'N 80°08'W	(Same position)
Local time:	1557	1748
Water Depth:	3500 feet	3500 feet

Due to failure of the starboard inverter, the dive was aborted after about 10 minutes of stationary bottom observations at a depth of 3500 feet. The bottom was covered with a light colored compact sand, assumed

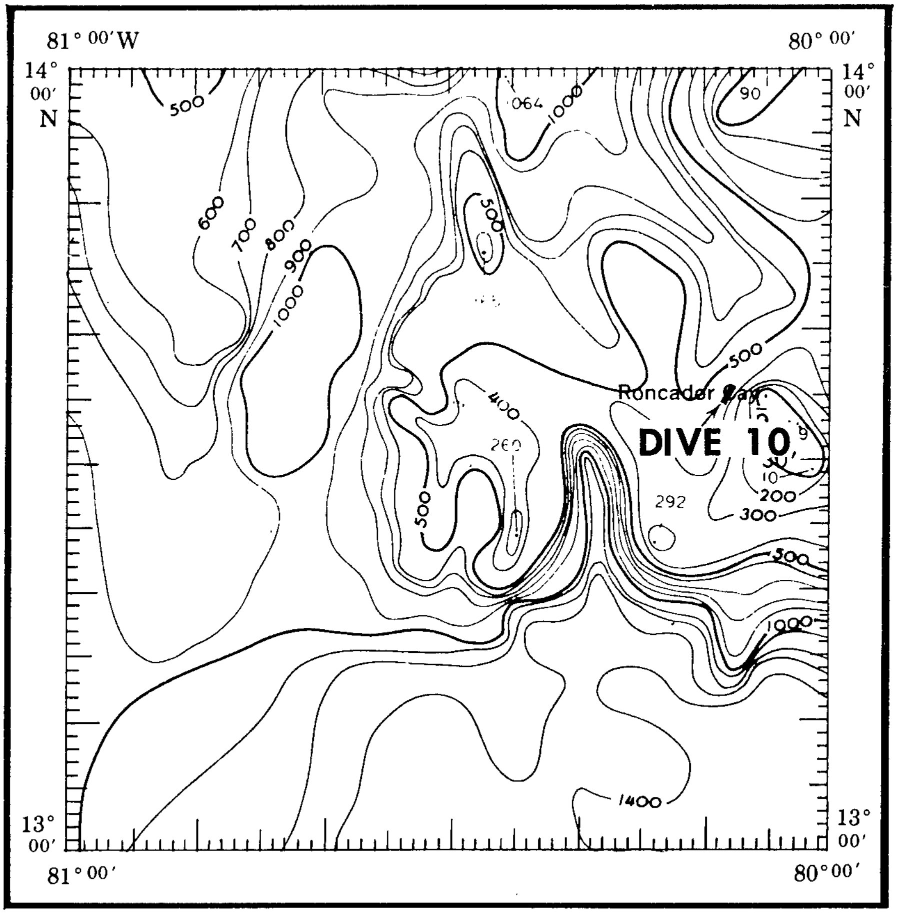


FIGURE 56. BATHYMETRY IN AREA OF DIVE NO. 10

to be a carbonate sand with a high content of skeletal debris. The bottom had a local slope of about 30°. Some turbulence and vehicle drift indicated a moderate current. During the first few feet of ascent the greater scope of view revealed that the vehicle had landed on a local ridge-like feature with the flanks dropping off sharply on either side. The slopes were estimated to be about 50°. A large scour or slump feature was seen on the up current side of the ridge.

At a depth of 2400 feet, a very dense "layer" was indicated on the upward looking echo-sounder, 80 feet above the vehicle. The lights were left on during transit through the layer to take motion pictures, but no organisms were sighted. The layer may have consisted of transparent organisms invisible to the observers or it may have been dispersed by the movie lights.

SUBMERSIBLE DESIGN CHARACTERISTICS AND PERFORMANCE

The following discussion concerns the various design features of DEEPSTAR-4000 (Figure 57) and their relation to a Deep Oceanographic Survey Vehicle.

Viewports

Since a primary function of a Deep Research Vehicle is to allow the scientist to view directly various ocean phenomena, the location of its viewports is one of the most important aspects of submersible design. Ports oriented with a vehicle's direction of travel are preferred since apparent curvature distortion is minimized.

DEEPSTAR-4000 (Figure 58) has 2 viewing ports aimed 21° below the

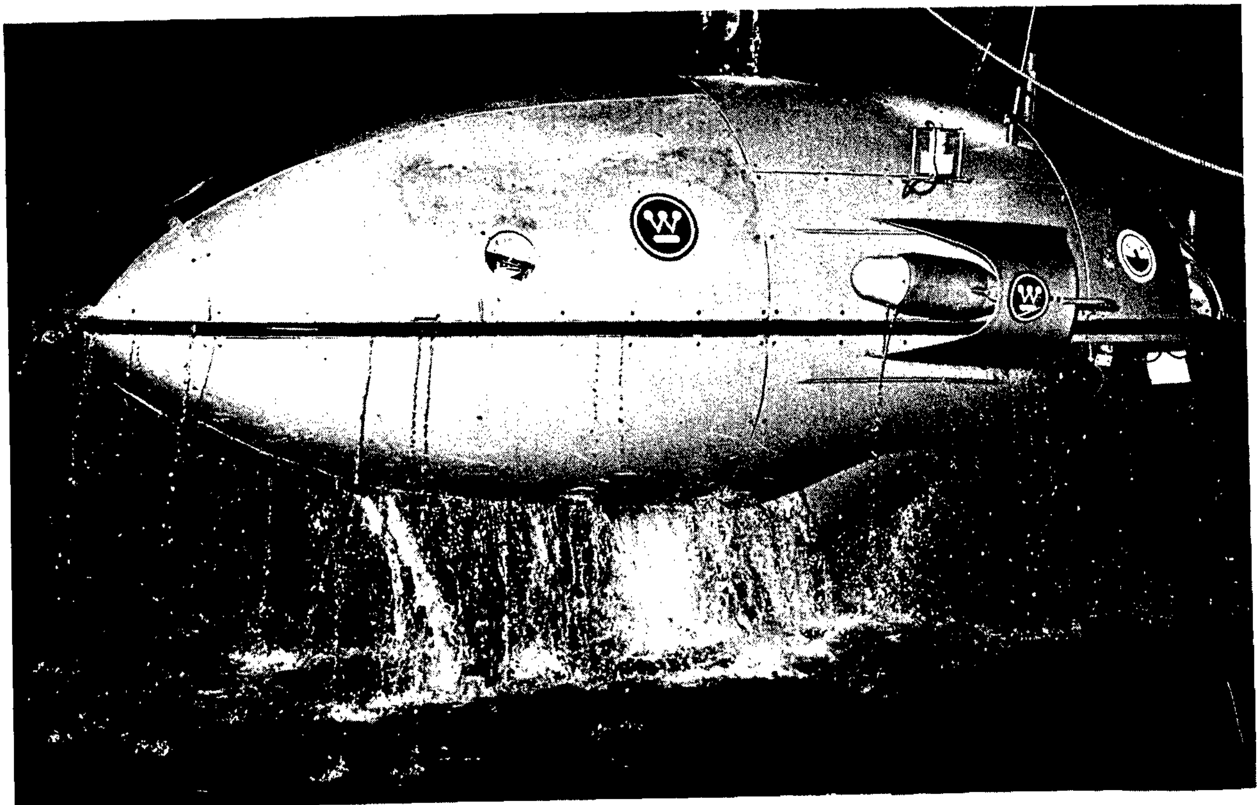


FIGURE 57. DEEPSTAR-4000 DURING RECOVERY AT NIGHT

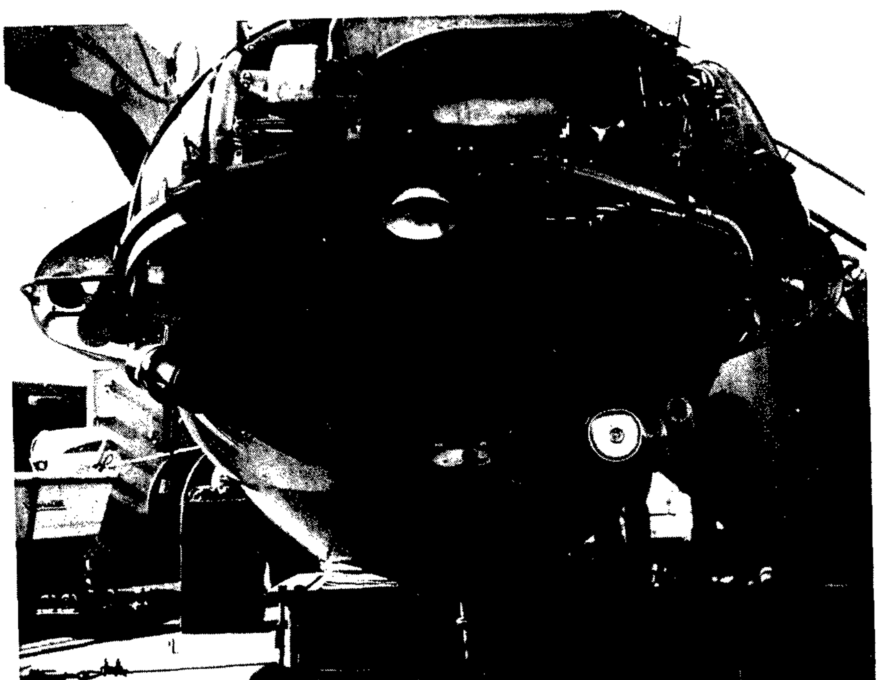


FIGURE 58. VIEWPORT AND CAMERA PORT ARRANGEMENT

horizontal; one is aimed 16° to port and the other is 16° to starboard of the centerline. Since the field of view of each port is 74° in water, the total field is 106° and the overlapping field is 42°. Hence, the pilot is able to use one port for operating the vehicle while the observer can use the other to view a part of the same area simultaneously. Both of these ports have an interior diameter of 4.33 inches, an exterior diameter of 11.1 inches, and are 3.9 inches thick. This dual-viewing capability is a significant asset since the pilot and observer can easily work together as an effective team in accomplishing the mission.

DEEPSTAR has a third, smaller port between the two viewports for cine-photography. This arrangement greatly facilitates obtaining high-quality motion pictures from reconnaissance dives. However, unlike the two viewports, the movie port is not equipped with a warm air blower. Condensation occuring when the vehicle travelled from cold water to warm water impaired motion pictures on one dive. Camera orientation does not allow coverage of the mechanical claw during sampling, but this is a minor detraction.

A major weakness of observation from DEEPSTAR is that the second observer has no view at all. This necessitates changing positions during the dive if both scientists are to make bottom observations.

A small upward port in the hatch would aid ambient light studies and in obstacle avoidance.

Speed

Based on bottom transits conducted during this series of dives,

the average cruising speed of DEEPSTAR was estimated at one knot. This was not sufficient to complete the bottom transits planned prior to the operation. When the vehicle was driven above one knot it either pitched or yawed significantly. It appeared that at speeds of one knot or more the pilot could control either the pitch motion or the yaw but not both. If the pitching motion was under control the yawing reduced speed of advance; if the yaw was controlled the porpoising motion adversely affected the motion pictures, since the angle of view was co..stantly changing, and level flight could not be maintained. The result of this situation is that any measurements or mapping, e.g. side-scanning sonar or stereo-photography, which require course keeping and maintaining near-constant altitude are seriously, if not hopelessly, constrained.

Payload

Payload--the amount of equipment in pounds not necessary for the normal operation of the vehicle--is 450 pounds. Although sufficient for this operation, future operations are envisioned which would require payloads of 1000 pounds or more. DEEPSTAR's payload could be increased by the addition of syntactic foam to the outside of the vehicle or by diving with only one observer. However, as in most of the relatively small Deep Research Vehicles, interior space also becomes very limited when additional equipment is installed.

A further hindrance to installation of internal equipment is the narrow access hatch. At 15 3/4 inches in diameter, it is the smallest hatch on any vehicle used by NAVOCEANO. Being four or five inches in diameter smaller than the hatches on other submersibles, the need for

major internal instrument modifications could easily occur.

Operating Depth

DEEPSTAR's 4000-foot operating depth was used as a basis in planning this operation. Assuming no other operational compromises were necessary, any increase in her depth capacity would increase the usefulness of the vehicle.

Endurance/Power

Cruising at an effective and useful speed of 1 knot, the maximum underway endurance experienced was about 4 hours. The longest on-the-bottom track, therefore, was about 4 nautical miles. Use of movie lights during part of bottom time causes the batteries to discharge to a critically low level and thus further limits the on-the-bottom time. In one instance this level was reached in only 2 1/2 hours of operation. It should be noted that ascent and descent do not generally require power consumption except when data is collected with sensors or photographs are made in the water column. Toward the end of the operation the previously scheduled dive sites were changed to accommodate the limited endurance of DEEPSTAR. The sites were moved toward shallower water so that only 2 or 2 1/2 miles were necessary to proceed upslope from deep water to the surface. It had been hoped to transit upslope perpendicular to the contours from a depth of 4000 feet to 600 feet or less, depending on the area. Considering the vehicle's payload and its available space, it may be worthwhile to use additional external batteries to power the lights needed for cine-photography on future dives of a similar nature.

Habitability

None of the smaller vehicles used by this project have been particularly comfortable for long dives. DEEPSTAR is no exception. Although the observer at the viewport is in a prone position on a foam contour couch, his effectiveness is still somewhat impaired by fatigue as a dive progresses. The second observer, who sits upright in the rear of the sphere between the pilot and observer, is free to monitor equipment and can be quite comfortable during any dive of reasonable length. Figure 59 shows the positions of the observers and the pilot.

During our 10 dives with DEEPSTAR the outside water temperature at many times was about 4°C. The interior of the submersible however, never dropped below 11°C. Hence, with a sweater or light jacket, the temperature inside the submersible was easily tolerated during deep dives.

On shallow dives (<200 feet) in warm water, the interior temperature reached 38°C with 100 percent relative humidity and impaired the observer's effectiveness. None of the NAVOCEANO observers experienced any problem with CO_2 build-up in DEEPSTAR as CO_2 level was monitored once an hour and, if necessary, corrected.

The depth, water temperature, and current speed indicators located above the pilot's viewport should be relocated in a place more easily seen by the observer at the other viewport.

Buoyancy Control

Ascent and descent are controlled by two releasable weights mounted forward and aft. A 220 pound descent weight is used to provide negative buoyancy. The weight mounted aft causes a stern-first spiral descent

at an angle of about 22 degrees. Nearing the bottom the weight is released and the vehicle becomes approximately neutrally buoyant. DEEPSTAR can then power down the remaining distance to the bottom. Fine buoyancy trim is accomplished by dropping small 3.4 pound weights or flooding any of eight small ballast spheres located outside the pressure hull. Pitch attitude of 30 degrees is accomplished by hydraulic transfer of mercury ballast between fore and aft reservoirs. At the conclusion of the dive, ascent is made by the release of a 187-lb. forward weight. Ascent attitude is about a 30° bow-up angle. The rate of ascent or descent may be controlled to some degree by changing the pitch of the vehicle with the mercury trim system or by using the main maneuvering motors. Normal descent rate is about 80 feet per minute while the ascent rate is near 50 feet per minute.

Maneuverability

DEEPSTAR has two 4.5 hp reversible motors to provide forward or reverse thrust. These fixed port and starboard motors allow DEEPSTAR to turn on its own axis. To traverse moderate slopes the mercury trim system can provide pitch control to ± 30°. However, the vehicle's ballast system must be used with the trim system to transit topographic slopes exceeding 30°. Trim weights can be dropped to provide positive buoyancy for going upslope, but the variable ballast tanks must be used to obtain negative buoyancy for downslope movement and to counteract loss of trim weights. With both systems, the vehicle's response is rather slow and maneuverability is severely impaired when operating in areas with steep slopes and rough topography.

Yawing and / or pitching at speeds in excess of one knot could

possibly be controlled by the addition of stabilizing fins. This modification is presently under consideration by Westinghouse.

As with other deep vehicles used by this project, DEEPSTAR's limited propulsion power becomes ineffective during operation in strong bottom currents and can cause a total loss in maneuvering control.

Maintenance and Serviceability

DEEPSTAR, compared to other vehicles used to date, appears to be better designed for ease of maintenance and servicing. The fiberglass fairing surrounding the pressure hull is easily removed providing access to control equipment and batteries. (Figure 60 shows DEEPSTAR with the fairings removed). During the one-month operation, no dives were cancelled due to unscheduled maintenance. One day of transit time was lost, however, when a crack in an exterior aluminum frame required special welding. The major operational problem encountered with the vehicle was a failure in the main power inverters which supply the two motors. Although this malfunction occurred twice during vehicle check-out on deck, a spare inverter was available and was installed in about 4 hours during the normal battery charging period. A third inverter failure occurred during the last dive before entering the Canal Zone and, due to the time schedule, the dive could not be repeated after repair.

SENSOR AND INSTRUMENT PERFORMANCE

The variety and type of scientific equipment on DEEPSTAR-4000 is typical of present contractor-furnished instrumentation. Due in part to a low payload and small volume, sophisticated sonars and television systems present on some other vehicles were not present on DEEPSTAR.

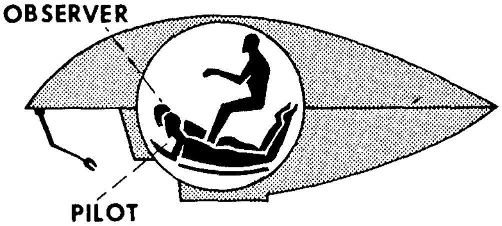


FIGURE 59. NORMAL POSITIONS OF PERSONNEL

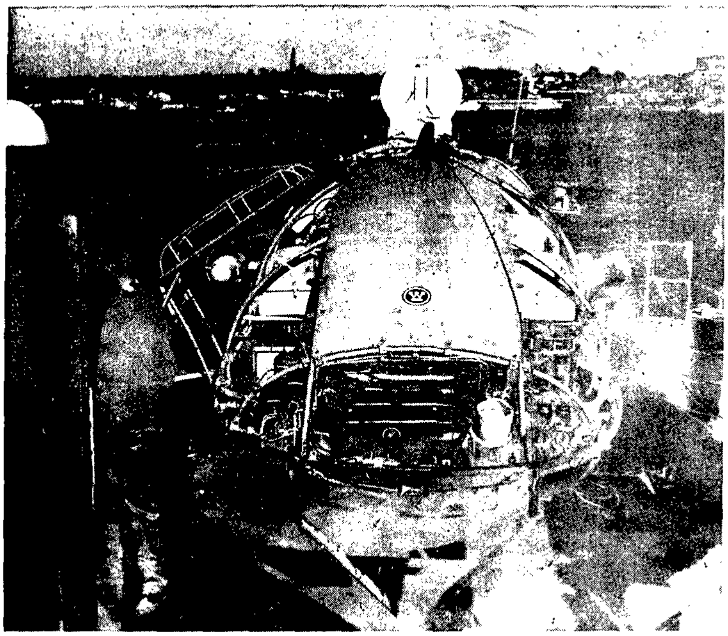


FIGURE 60. FAIRING REMOVED FROM DEEPSTAR FOR EASE OF MAINTENANCE

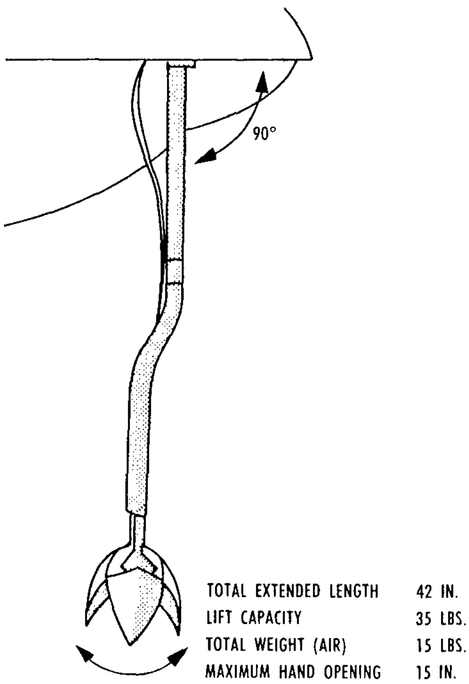


FIGURE 61. RELEASABLE MANIPULATOR ON DEEPSTAR-4000

The photographic system on DEEPSTAR is far superior to that on any other submersible NAVOCEANO has used to date.

Navigation

Prior to our third dive, the only instrument on the submersible to provide course information was an unreliable magnetic compass. Results of the first two dives were severely impaired by dependence on this instrument. However, a Sperry Mk27 gyrocompass was installed for use on the last 8 dives and proved to be very effective and reliable.

During all dives DEEPSTAR was equipped with a 27 kHz pinger which was tracked by a directional hydrophone from the small boat. It had been planned that the small boat would maintain a position over DEEPSTAR while SEARCH TIDE, using radar, would track the small boat. Unfortunately, the LORAN-A system on SEARCH TIDE did not offer a repeatability to fix the support ship with the necessary accuracy for meaningful tracking results.

Hence, the method of reconstructing DEEPSTAR's track for each dive had to depend on the combination of a number of inputs: LORAN-A position at launch; LORAN-A position at recovery; manually-recorded gyrocompass information on the submersible, and bathymetric information from both DEEPSTAR and SEARCH TIDE.

To overcome this weakness and improve future dive results, much greater emphasis will have to be placed on navigation and tracking capabilities.

Depth and Altitude Sensors

DEEPSTAR has 3 Edo transducers: forward-, upward-, and downward-looking. These can be used with a strip chart recorder inside the

submersible to determine the depth, altitude, or distance from an object in front of the submersible. However, only one of these parameters may be measured at a time. In addition, to the Edo system, two pressure gages in the submarine indicate the depth. One is calibrated in feet from 0 to 5000 feet, and the other in meters. The accuracy of the pressure sensors is questionable. Comparison of the upward echo-sounder information with the two pressure gages usually yielded three different depths at any one point. After some experimenting, the best method of monitoring DEEPSTAR's depth was determined to be the upward echo-sounder which yielded a permanent, continuous record of the vehicle's depth below the water surface during each dive.

Communications

DEEPSTAR is equipped with a 4-watt underwater telephone which is used sparingly for two reasons. First, under most conditions, it is difficult to understand a conversation unless the sender speaks clearly and slowly. Second, the pilot must devote his full attention to controlling the vehicle. With very few exceptions, the only communications between DEEPSTAR and SEARCH TIDE during a dive were depth checks about once every half hour or perhaps just a "Delta 5" which means everything is normal.

DEEPSTAR also has a battery-operated radio for communication with the support ship when surfaced.

Manipulator and Bottom Sampling Devices

A single mechanical arm (Figure 61) with only three degrees of freedom can be installed in about three hours on DEEPSTAR. This arm

weighs 15 pounds, has a maximum reach of 42 inches and can lift about 35 pounds. In most cases, due to the limited dexterity of the arm, the vehicle is maneuvered in conjunction with the arm to obtain a sample. A basket, which can extend from the port side of the vehicle, is used to store samples. At the outward end of the arm is an orange peel sampler. Experience showed that the sampler's fingers were too weak. In trying to pick up a rock sample, the fingers were often bent and forced out of alignment. A more rugged arm with increased dexterity would be far more effective and a variety of hands or end samplers is also desirable.

Illumination

Exterior illumination is provided by 4 French-made quartz-iodide lamps. During normal running, one 1000-watt lamp, located forward and on the center line of the vehicle, is used. Immediately below is a 2500-watt quartz-iodide lamp used when taking motion pictures. There are two additional 500-watt quartz-iodide lamps, one located between the ports and the other on the starboard side and forward. These lights were sufficient during the NAVOCEANO operation and provided sufficient illumination for our reconnaissance mission. In addition, two 200 watt-second strobes are mounted on the bow of the vehicle and are synchronized with the 70mm camera.

Photography

A Hydro Products PC-780 70mm camera with a film capacity of 100 feet (400 exposures) is mounted forward on the starboard side. Used for still photography, film advance is controlled from inside the vehicle

and the focus can be changed during the dive.

A Bell & Howell Model 70HR 16mm movie camera is located inside DEEPSTAR. This camera has a 400-foot film capacity which can be extended merely by replacing the exposed film magazine during the dive. The port located between the observers' and the pilot's port is provided for cine camera operations. This is an extremely effective arrangement apparently available only on DEEPSTAR-4000. Operation of the camera is controlled by the observer who pushes a button when the camera is required. In addition, the camera port views essentially the same area as the observer. DEEPSTAR's cine camera arrangement is unique and is strongly recommended in any future vehicle design.

Oceanographic Sensors

DEEPSTAR-4000 has a Savonius rotor located on the starboard side. This gives a readout of current speed and has an odometer for gross measurement of the distance covered by the vehicle during a dive. A Hydro Products temperature probe provides water temperature information. An inclinometer can be used to obtain a gross measurement of the bottom slope. There are no recorders located within the submersible for permanent records of these parameters.

SURFACE SUPPORT

During this operation DEEPSTAR-4000 was supported by the M/V SEARCH TIDE (Figure 62). Major characteristics of this vessel include: length, 155 feet; beam, 36 feet; displacement, 199 tons; maximum draft, 11 feet. This vessel, powered by two Caterpillar 1000 horsepower (max)

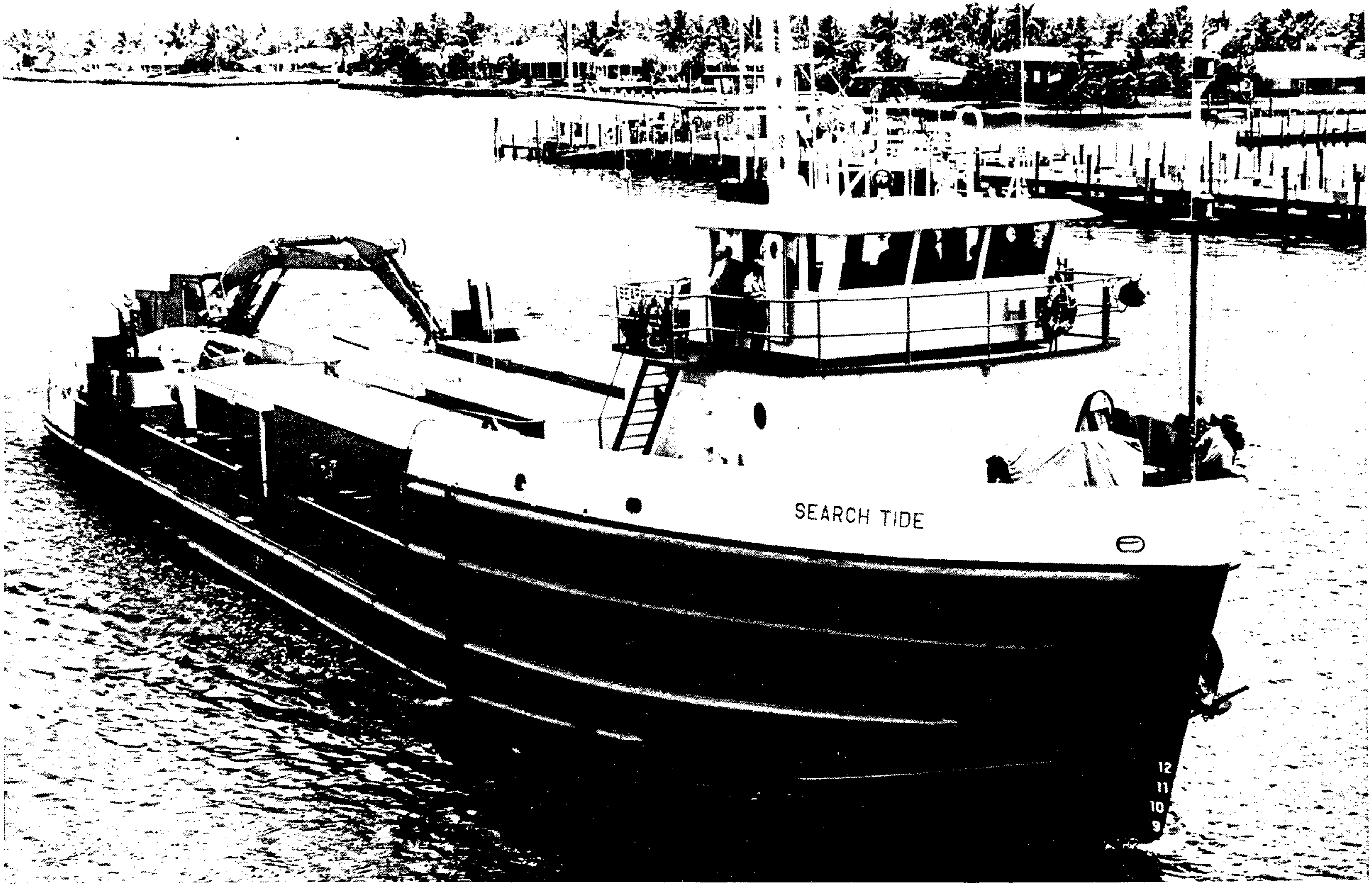


FIGURE 62. M/V SEARCH TIDE

diesel engines, has a transiting speed of 12 knots and a range of 5000 miles. This speed and range proved to be most acceptable for the NAVOCEANO operation. The vessel's bridge is located on the 02 level, crew's quarters on the 01 level, and a galley and office are located on the main deck. Four vans located on the fantail provided living space for the submersible crew and NAVOCEANO personnel. Vans housing a dark-room, machine shop, and a maintenance shop for DEEPSTAR's electronics also were located on the ship's fantail. An instrument van for the contract personnel was provided; however, no area for office space was available for the scientists.

The launch and recovery system for DEEPSTAR-4000 is provided by a modified Koehring articulated crane with a lift capability of 25 tons and pneumatically operated cradle. This operation requires two line handlers, a crane operator, and a diver for connect and disconnect of the lifting/launching hook in the water. As with all of the submersibles, operations in sea state 4 and above are hazardous because of weaknesses in the launch and recovery system. The different motion between the submersible and support ship creates a dangerous situation when short period waves, 4 feet or higher, are present. Hence, no dives are attempted when the seas are greater than 4 feet with periods less than 10 seconds.

Manpower requirements to support DEEPSTAR-4000 at sea are presented in Table IV. Seven people are required to operate the support ship SEARCH TIDE while a crew of 12 are used to maintain the submarine. Since about a third of the support crew are kept on rotation, however, the number of people actually onboard to support the submersible varied between 8 and 10.

Navigation equipment on the support ship included a Decca DX LORAN-A navigation set, and a Decca RM314 Radar. Ship-to-Shore communication on SEARCH TIDE was provided by an Apelco AE 190 CM marine radio telephone, but limited range and lack of proper crystals yielded marginal results in some areas. (Since our operation, this unit has been replaced by a single side band radio.)

Better navigation, possibly through use of a satellite system, would have helped this operation. There is a need on the support ship for a tracking system to obtain continuous range and bearing to the submersible. Battery-operated citizen band radios were used for communication between the support ship and the surfaced vehicle and for communications with the small boat during a dive.

TABLE IV

SUPPORT PERSONNEL

DEEPSTAR

- Supervisor
  - Maintenance Chief
    - Electrical (3)
    - Mechanical (3)
  - Chief Pilot
    - Pilots (2)
  - Service Assistant

SEARCH TIDE

- Master
  - Chief Engineer
  - 1st mate
    - Seamen (2)
  - Cook
    - Cook's Helper

SUMMARY AND CONCLUSIONS

Adding to the general conclusions obtained through the use of ALVIN (Busby, Merrifield, 1967) and enhanced by each subsequent submersible field study, this DEEPSTAR operation has shown the feasibility of extended at-sea diving programs. The reliability of DEEPSTAR, the expertise of the support personnel, and the availability of extensive support facilities were necessary factors contributing to the success of this operation.

Launch and Retrieval

Although the submersible was nearly always ready to dive, a number of scheduled dives were cancelled due to adverse weather conditions. Since the launch and retrieval capability is the most sensitive part of the total system, the "Go-No Go" decision in rough weather is based primarily on this capability. While the articulated crane on SEARCH TIDE can be compared favorably with the launch and retrieval systems used for the other submersibles leased by NAVOCEANO, 4 foot seas with 4 to 6 second periods were enough to cause dive cancellation (1). This constraint will have to be overcome or at least reduced before deep submersibles can approach full utility.

A handling system under development by Mr. Edward Link for use with DEEP DIVER (PL-4) includes vertical damping and a "connect-disconnect" feature that does not require swimmers. While advances of this type will never completely suppress the effects of the air-sea interface, they will increase the number of vehicle operating days and should be at least a short-term goal of all submersible operators. Submerged

(1) When operating in the Pacific, DEEPSTAR has often been launched and recovered in 10 foot seas, but wave periods were 10-12 seconds.

launch and retrieval systems, to divorce this procedure from the air-sea interface, may be the ultimate answer. This must be considered as a long range goal, since present Navy certification requires fail-safe devices to allow a submersible to return to the surface in the event of a major malfunction. Under this circumstance, a submerged recovery system would not be more advantageous than a surface-oriented system.

Navigation and Positioning

Another major weakness experienced on this operation concerned the submerged navigation and positioning of DEEPSTAR. Again, this weakness has been more the rule than the exception on all DRV leases by NAVOCEANO. After the second dive a gyrocompass was installed and did provide DEEPSTAR with enough navigating ability to head toward shallow water after using LORAN-A (or radar), bathymetric charts and SEARCH TIDE's fathometer for launch site determination.

As stated previously, tracking of the submersible during a dive was accomplished using a directional hydrophone from the small boat. Track reconstruction, however, proved all but impossible due to combined errors in (1) relative bearing between the small boat and the submersible, (2) assumed depth of the submersible, (3) radar fixes between small boat and SEARCH TIDE and, (4) LORAN-A or radar positions of SEARCH TIDE.

Much better results have been obtained when the directional hydrophone is mounted on the support ship, thereby removing radar range and bearing errors to the small boat. In addition, signals from a transponder (or a precision pinger synchronized with a master clock -

Marquet et al, 1968) mounted on the submersible can be used to provide a continuous trace of slant range between the support ships and the vehicle. If a surface navigation net of high accuracy (eg. Decca MK XII) is not available, a second transponder or precision pinger, or an anchored radar reflector, should be planted for use as a fixed reference for relative positioning of the surface support ship.

Tracking is, at best, a poor method of positioning a vehicle while it is conducting a survey. In instances when the submersible will be operating in the same area for a number of days, a network of acoustic bottom beacons should be planted for real-time positioning from within the submersible.

Vehicle Characteristics

Particular characteristics of the DEEPSTAR-4000 vehicle that should be included on a DOSV include the blower-equipped, forward viewports with overlapping fields of view and the third port for cine-photography. The use of contour couches with the viewports also indicates some concern for human engineering which is notably lacking in most other vehicles. Also, by virtue of her small size and smooth configuration with limited protuberances, DEEPSTAR is able to work close to the bottom regardless of topographic roughness. On the other hand, the low payload and rather limited buoyancy control are DEEPSTAR features that should be avoided on a Deep Oceanographic Survey Vehicle.

As noted previously, the effectiveness of any submersible as a Deep Oceanographic Survey Vehicle is severely hindered by lack of an all-weather launch and retrieval system and by absence of a precise

positioning system. However, these criticisms should not be construed as directed solely toward DEEPSTAR since NAVOCEANO has experienced similar conditions on all leases to date. Further, DEEPSTAR-4000 was not designed as a survey vehicle and it would be unfair to assume that this submersible could meet all of NAVOCEANO's requirements.

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ACKNOWLEDGEMENTS

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APPENDIX I Sample Analyses

Dive 3 - (Figure 17)
Sample 3a. (#1)

Nodule. (Depth 1500 feet) Moderately dense. Laminar with aragonite partings. Exterior surface slightly weathered and oxidized. Interior dense and unweathered. Francolite is the predominant mineral alpha-FeOH may be present in the crust as a weathering product. No manganese was detected by X-ray analysis.

Dives 4 & 5 - (Figure 26)
Sample 4a. (#2)

Nodule. (Depth 3600 feet) Friable. Highly weathered and oxidized crust. Interior slightly less weathered and oxidized. Typical onion structure of mid-depth Fe-Mn nodules. X-ray analysis shows geothite, quartz (residual), and an unidentified 10 A phase which may be a primitive manganese hydroxide hydrate.

Sample 4b - (#12)

Friable phosphate nodules. (Depth 3600 feet) Francolite and iron-manganese minerals.

Sample 5a - (#3)

Carbonate cobble. (Depth 3800 feet) Dense. Uniform texture throughout. Calcite, quartz in the ratio 5.5:1. A major unidentified phase is present.

Sample 5b - (#10)

Phosphate nodules. (Depth 3700 feet) Friable. Predominant mineral is francolite. Significant iron-manganese minerals present.

Sample 5c - (#11) (Not shown in Figure 26)

Carbonaceous sandy clay with phosphatic, friable nodules (Depth 3700 feet) Clay fraction predominantly low-Mg calcite with secondary high-Mg calcite, illite, kaolinite, chlorite, and a montmorillonite or mixed-layer clay minerals. Sand fraction predominantly low-Mg calcite and secondary quartz, minor aragonite, and possible dolomite. Phosphate pebble composed of francolite and iron-manganese minerals.

Dive 6 - (Figure 31)
Sample 6a - (#4)

Calcarenite. (Depth 2550 feet) Slightly weathered. Minor manganese staining. Insoluble residue: montmorillonite; illite; kaolinite; chlorite; quartz; feldspars. Carbonate fraction: 44% aragonite; 56% calcite w/$\sim$8 wt. % $MgCO_3$.

Dive 7 - (Figure 45)
Sample 7a - (#7)

Oolitic limestone. (Depth 2500 feet) Dense. Slightly weathered. Thin manganese coating with Fe-Mn staining or replacement throughout. Insoluble residue: illite; montmorillonite; kaolinite; chlorite; quartz; feldspar. Carbonate fraction: 5% aragonite; 19% calcite w/$\sim$ 2 wt.% $MgCO_3$ 76% calcite w/$\sim$10 wt.% $MgCO_3$.

Sample 7b - (#6)

Cobble. (Depth 1500 feet) Dense. Active manganese replacement of primary minerals. Manganese minerals apparently X-ray amorphous. Carbonate fraction: Low-magnesium calcite. Francolite present as minor component.

Dive 9 - (Figure 55)
Sample 9a - (#13)

Cobble. (Depth 1800 feet) Active Mn replacement. Amygdules of francolite in a calcite matrix. Calcite - 45% with$\sim$2 wt.%$MgCO_3$ and 55% with $\sim$ 5 wt.% $MgCO_3$.

Sample 9b - (#5)

Coral. (Depth 1600 feet) Slightly weathered. Minor iron and/or manganese staining. Insoluble residue: illite; kaolinite; chlorite; expandable clay; quartz; feldspar. Carbonate fraction: 22% aragonite; 78% calcite w/$\sim$13 wt.% $MgCO_3$.

Sample 9c - (#9)

Calcarenite. (Depth 1350 feet) Moderately weathered. Considerable Mn staining. Insoluble residue: Illite; montmorillonite or mixed-layer clay mineral; kaolinite; chlorite; quartz; and feldspar. Carbonate fraction: 15% aragonite; 21% calcite with 1 wt.% $MgCO_3$; 64% calcite with $\sim$10 wt.% $MgCO_3$.

Sample 9d - (#8)

Calcareous sand. (Depth 700 feet) W/filamentous organic matter; bryozoan or echinoderm plates. Insoluble residue: illite; kaolinite; chlorite; mixed-layer clay mineral; quartz; and feldspars. Carbonate fraction: 72% aragonite; 4% calcite with 1% $MgCO_3$; 24% calcite with $\sim$13 wt.% $MgCO_3$.

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13. ABSTRACT

The U.S. Naval Oceanographic Office used the Westinghouse submersible DEEPSTAR-4000 for 13 dives during October and November 1967. Marine geology, biology and the physical properties of the water column were studied on the 10 deep dives of this series.

These dives were accomplished along the east coast of the United States and in the Caribbean. Great similarities in the bottom features at widely separated sites as well as dissimilarities in adjacent areas are particularly noteworthy.

During this operation DEEPSTAR-4000 was evaluated as a Deep Oceanographic Survey Vehicle (DOSV). The lack of an all-weather capability and the rather limited payload hampered this study but the overlapping fields of the viewports and the ability to operate in very close proximity to the bottom regardless of terrain, are desireable features that should be included on any future DOSV.

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MANNED SUBMERSIBLE						
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